Carnstone

LoCaT
The Low Carbon TV delivery Project

Quantitative study of the GHG emissions of delivering TV content

Final Report – Version 1.1
The LoCaT Project

Carnstone LoCaT

Executive summary

With recent media attention about the impacts of streaming, as well as a plurality of different TV delivery methods in Europe, the LoCaT project set out to estimate and compare the greenhouse gas (GHG) emissions associated with serving TV content across different platforms. We found that delivery of content via digital terrestrial television consumed substantially less energy, when compared to IP-delivered methods. Our modelling suggests this will remain the case in the long term under a range of scenarios.

In this report, we outline the results of the study, as well as the approach taken to model each of the delivery cases. This model draws on earlier research and adopts an attributional life-cycle assessment (LCA) methodology. We considered the viewing of linear TV via Digital Terrestrial Television (DTT) and managed IPTV, as well as streaming and on-demand viewing that is delivered via the internet, referred to as over-the-top (OTT) services. OTT services include subscription video on demand (SVOD) such as Disney Plus and Amazon Prime, as well as broadcast video on-demand (BVOD) such as catch-up content from national channels such as SVT Play in Sweden or BBC iPlayer in the UK.

Primary data was available for some components of the delivery system from the LoCaT Project Sponsors, but we also drew upon market research published by organisations such as European Audiovisual Observatory, BARB, Ofcom, and the European Broadcasting Union to understand TV viewing behaviour across Europe. Subsequently, we drew upon and compared our analysis to other studies into the GHG emissions of TV viewing, notably the academic paper produced in partnership with the BBC *Using Behavioural Data to Assess the Environmental Impact of Electricity Consumption of Alternate Television Service Distribution Platforms* (2021).

The LoCaT Consortium

The LoCaT Project is a collaborative initiative from a few leading European players of the TV and Broadcast industry who have commissioned Carnstone to assess the environmental carbon emission impacts of various TV delivery methods. The Project Sponsors are:

- **Association Technique des Editeurs de la TNT (ATET)** – the trade organization of TV channels delivered via DTT in France
- **Broadcast Networks Europe (BNE)** – the trade organization of DTT network operators in Europe
- **ORS Group** – the main Austrian DTT network operator
- **Quadrille** – a French content delivery technology provider
- **Salto** – a French OTT streaming platform

The Project Sponsors contributed primary and secondary data for the analysis, and engaged those linked to their organisations to provide input and expertise where there were gaps in knowledge. Sponsor inputs were validated by Carnstone, who also sourced data independently where there were gaps in data available from Sponsors. Assistance to the Sponsors for project initial set up and during the execution phase was provided by Blue Maple Ventures (BMV)

About Carnstone

Carnstone is a management consultancy specialising in sustainability and corporate responsibility. In partnership with the University of Bristol’s Computer Science Department and leading media organisations, we developed DIMPACT (https://dimpact.org). DIMPACT is a web-based tool that allows large media companies to estimate the GHG emissions of serving their digital content.

This report was authored by William Pickett, Alejandro Fiocco, Glynn Roberts and Ben Horn from Carnstone, with technical input from Professor Chris Preist, Dr. Daniel Schien, and Paul Shabajee from the University of Bristol.

Below we summarise the headline findings.

OTT streaming and managed IPTV are associated with a higher energy consumption, when compared to linear DTT delivery.

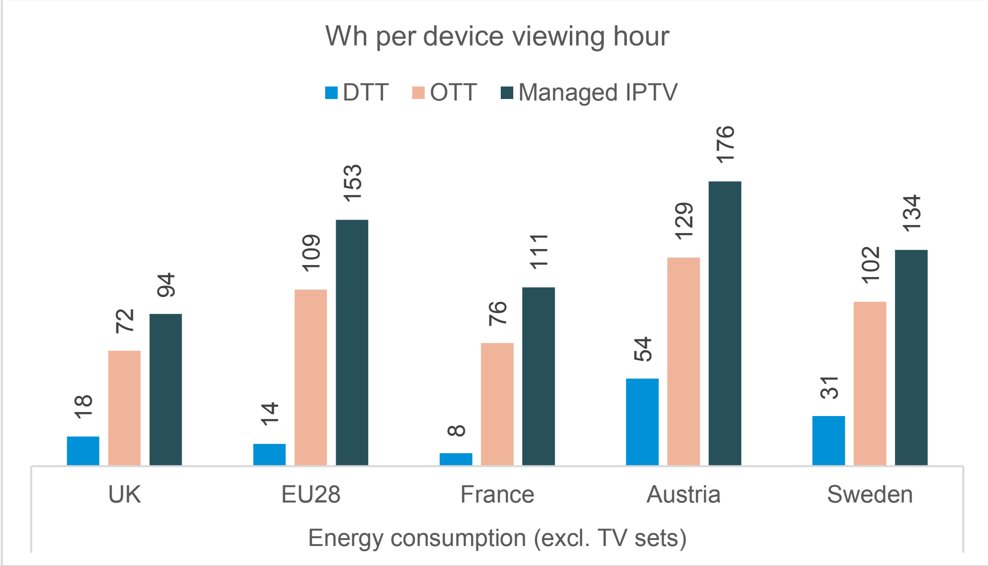
We produced estimates for each individual EU country, but also produced pan-European estimates for the EU28. On average across Europe in 2020, we estimated that the energy consumption associated with one device viewing hour of DTT was 14 Wh, 109Wh for OTT and 153Wh for managed IPTV. This equated to 3g of carbon dioxide equivalent emissions (CO_2e) for DTT, 26gCO_2e for OTT and 37 gCO_2e for IPTV. This excludes the energy consumption of the television itself.

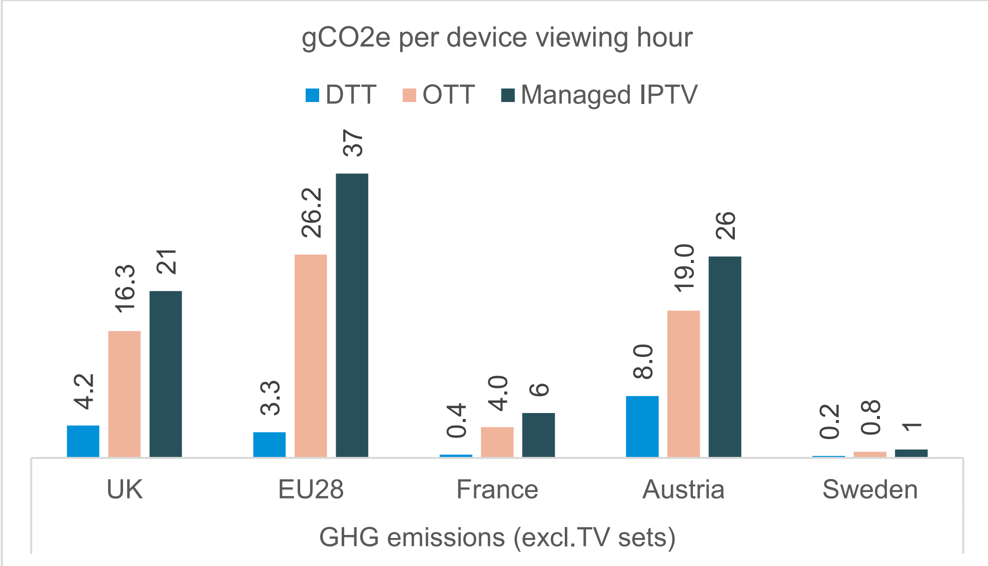
Variation between countries in terms of energy consumption was driven by differing viewership behaviour (times and penetrations of each delivery method), usage of in-home peripherals as well as the proportion of the internet traffic used for OTT and IPTV viewing and thus allocation of the energy consumption of internet networks.

There are differences in GHG emissions between countries mainly owing to the differences in carbon intensity of the national electricity grid. For example, the charts on the bottom right show that overall emissions were lower in France and Sweden than the UK and EU28 averages. This was due to electricity grids in these countries being less dependent on fossil fuels.

A majority of energy used for TV viewing is consumed by devices in the home, such as set-top boxes

This finding applies across all delivery methods. However, our analysis suggests that DTT viewership consumption is more energy efficient due to its simplicity. DTT efficiency is due to most DTT households using a passive aerial connection to access the network, usually with a direct connection to TV sets without the need for peripherals. This is in contrast to managed IPTV that requires using a share of the in-home modem-router and – currently across European markets – a set-top box to decode content and offer additional features such as OTT apps.





Whilst excluded from the main analysis in this report, television sets cause a notable increase in energy consumption and therefore GHG emissions. We excluded TV sets from this analysis in order to compare different delivery methods, but the results suggest that consumers' choices of viewing devices will have an impact on overall emissions. We do consider the power of TV sets in order to compare our results to other studies that use a television.

A change in proportion of TV content delivered via DTT networks may have an impact on the GHG emissions of the TV industry.

In addition to the baseline results for 2020, we analysed the impacts under a series of future possible scenarios of TV market development and viewership behaviour. This allowed us to consider how the potential carbon impacts of TV viewing and delivery patterns may change over time in the short to medium term (2020 to 2035).

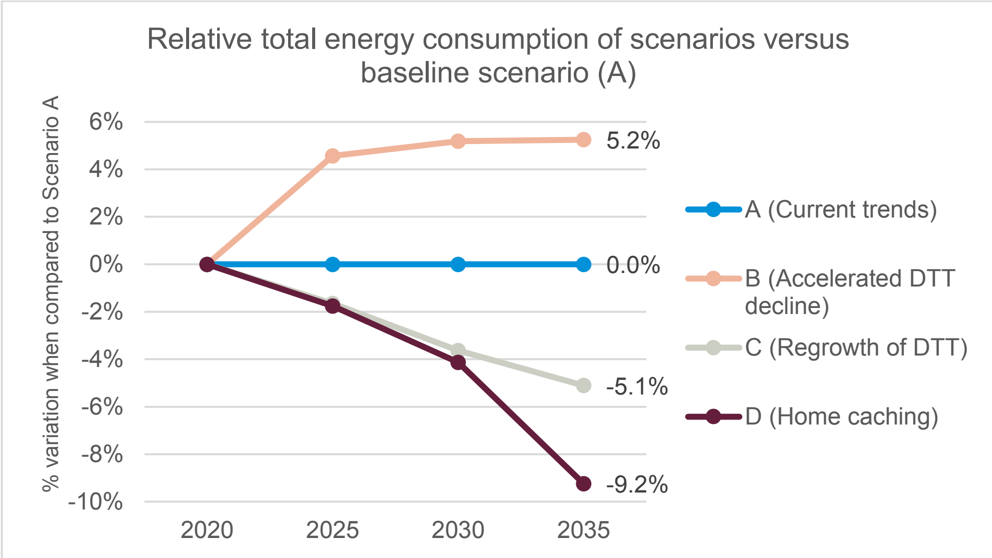
In many countries across Europe (and likely around the world), there has been a steady decline in viewing of linear television – from 95% in 2015 to 90% in 2019. However, these figures show that linear viewing still makes up the largest proportion of overall viewing. This proportion of linear viewing may continue to decrease. However, extrapolation of current trends suggests that this is likely to remain a high proportion of viewing over the medium term (approx. 75% if current trends continue).

If linear viewing declines, but total viewing hours remains the same or slightly increases, this will mean an increase in non-linear viewing via OTT delivery. If DTT declines, the shortfall is taken up by more carbon intensive viewing options such as OTT, and so the overall TV delivery emissions increases using our current allocation method. This was confirmed in our scenario analysis, where the scenario with rapid DTT decline (B, right) suggests higher overall emissions than scenarios where DTT remains a key part of the TV delivery landscape (C and D). In Scenario D, we look at a speculative 'home caching' technology that allows viewers to store VOD content locally after receiving content via DTT networks, thus increasing the viewing from DTT delivery whilst reducing viewing via IP networks.

Qualitatively, we speculate that viewing of linear television at peak times via DTT (and other non-IP networks) may have the added benefit of reducing the demands placed on IP networks. Whilst data consumption of IP networks is used as a proxy for energy consumption, it's becoming increasingly clear that peak demand is what is driving further expansion and thus energy consumption.

This was not addressed quantitatively in this study, because there are many drivers of increasing data demand (e.g., AI, gaming, and virtual/augmented reality) so was beyond the scope of this project to understand DTT's role in this. Understanding the impact of non-IP delivery modes in reducing peak demand is an area for further research, possibly benefitting from a different methodology than the attributional life-cycle assessment approach used in this study.

A further trend observed is an increase in managed IPTV penetration. Linear viewing via IPTV makes use of multicast technology, meaning that encoding of a channel is only sent once via the IP networks, reducing data transmission in the core network. However, this efficiency does not offset the energy consumed by IPTV set-top boxes, which are required for IPTV viewing. This increases the overall energy consumption of this delivery method when compared to both DTT and OTT, and thus the scenarios with higher IPTV viewership.



The results in this study align closely with other similar studies looking at video streaming, however we offer one of the first evaluations of the carbon impacts of managed IPTV

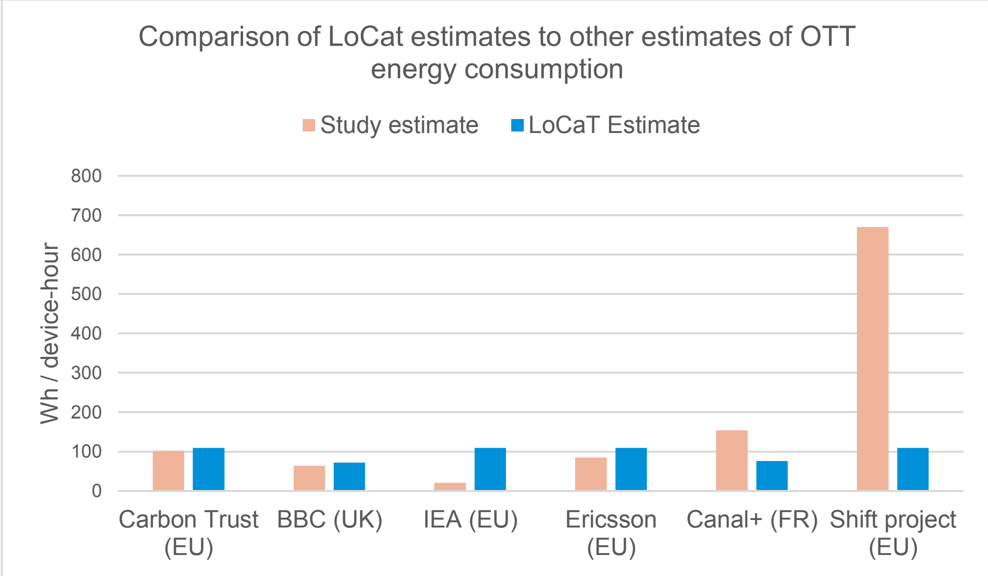
There has been significant media attention regarding the carbon impacts of OTT video streaming. This has led to a series of in-depth studies that aim to get a scientific understanding of the impacts of this delivery methods. The latest studies have been completed by the Carbon Trust and the BBC. The other two delivery methods considered in this study have not received the same intensity of analysis. The BBC have provided the most comprehensive study of DTT network carbon impacts.

We see good alignment with the Carbon Trust and the BBC studies for both our DTT and OTT models, which is explored further in this report. In general, our results are within the same order magnitude of other estimates, and especially close (within 12%) to recent studies such as Carbon Trust White Paper and the BBC's updated 2020 results[1]. This gives us good confidence in the modelling that we have conducted, despite using slightly different methodological approaches.

Like other studies on this topic, we stress that modelling complex systems has a level of uncertainty. We would welcome more primary data from media companies and internet service providers.

The LoCaT study was able to use primary data from Project Sponsors (validated by Carnstone) for the modelling of DTT networks, as well as some research conducted by Sponsors on viewership behaviour in countries such as France. In other cases, we used publicly available data for our model inputs which aimed to give country- and Europe-level estimates.

In our modelling, there is specific uncertainty and lack of country-specific data on our estimates of IP network energy consumption, as well as data on the mix of devices being used to access and view content. There is especially uncertainty in the scenarios inherent in any speculation about future trends. We stress that the scenarios are not opinion (nor that of the Project Sponsors) about what will happen in the future, but should be understood as a thought experiment to explore the carbon impacts of plausible future evolutions of TV viewership in Europe.



An important way to reduce this uncertainty is to increase transparency from the organisations holding primary data on viewership behaviour and end-user devices. Internet service providers may also be able to play a key role in providing standardised data on the energy consumption of their networks, as well as sharing how changes in viewership behaviour (and thus demand for data) may affect network dynamics.

National-level bodies undertaking research into TV viewing behaviour should also continue to expand their measurement tools to track viewership of VOD as well as linear and time-shifted content across all screens, for example four-screens monitoring being pioneered by organisations such as BARB in the UK. A natural progression of this LoCaT project is to validate the results of the study with primary, organisation-level data.

[1] https://www.bbc.co.uk/rd/blog/2021-06-bbc-carbon-footprint-energy-envrionment-sustainability

This transparency would give a higher level of confidence to organisations and policy makers that are making decisions based on the climate impacts.

Regulators could also play a role in defining standardised reporting frameworks and encouraging all relevant parties to provide data against these frameworks.

Despite the uncertainty stated here, the alignment with other studies and the scenario results gives us confidence in the results. The scenarios provide a good stress test, as they examined how the model would react under different scenario parameters. Given that the modelling was stable under these various input parameters, we believe this demonstrates robustness in the qualitative conclusions.

Contents

1 Introduction

We have learned many things during the pandemic, not least that TV is an important part of people's lives and society, be it in the shape of news, entertainment, education, or public service. The viewing of audio-visual content now happens anytime, anywhere through a mix of established and emerging technologies, ranging from traditional broadcast delivery methods, such as digital terrestrial TV, satellite, and cable, through to on-demand and live content delivered via digital streaming and (managed) IPTV. TV viewing is no longer limited to one location or one device.

The evolution of TV delivery and consumption habits and technologies has happened in parallel with another significant evolution; the rising concerns around climate change and specifically the greenhouse gas (GHG) footprint of materials and technologies. Much has been written about the environmental impact of the information and communications technologies (ICT) sector, but the carbon footprint of the delivery of TV content remains under-researched.

Media coverage in recent years has claimed that the GHG impacts of video streaming via IP networks has been found to be significant. However, many of these claims have been refuted by organisations like the International Energy Agency (IEA)[2] and the World Economic Forum, backed by primary data. This means that it is important to have accurate, factual estimates of the emissions associated with the delivery of TV.

In response to this, a consortium of leading European players in the TV and broadcast industry known as LoCat ('The Low Carbon TV Delivery Project') commissioned Carnstone – with the support of computer scientists at University of Bristol – to conduct a technical study to assess the GHG footprint of various TV delivery formats.

1.1 Study objectives

The objectives of this study were to answer the following two questions:

1. What is the GHG emissions caused by the delivery of one hour of television content via each of the following delivery methods (DM):

- Digital Terrestrial Television (DTT)
- Over-the-top (OTT)
- Managed Internet Protocol Television (IPTV)

2. What are the total GHG emissions caused by the delivery of TV content for each of the DMs above, both currently and in the medium and longer terms (2020-2035).

1.2 Previous studies

This project builds upon existing work completed both as research and practical tools to help organisations measure and understand the emissions associated with delivering TV content. This work draws heavily upon the work completed by BBC R&D, notably their White Paper 372, which outlines the energy consumption of BBC TV delivery across different methods[3]. The authors of this study were consulted throughout this study. We also drew upon a recent White Paper from the Carbon Trust: *The Carbon Impact of Video Streaming*[4], which also provides a valuable contribution to the understanding of

[2] See, for example, the IEA's response to the Shift Project analysis of video streaming emissions, https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[3] https://www.bbc.co.uk/rd/publications/whp372_behavioural_data_environment_impact_electricity_consumption_tv_platforms

[4] https://www.carbontrust.com/resources/carbon-impact-of-video-streaming

video streaming in Europe. In addition, we also drew upon other academic and technical research to gather data and develop our modelling approach.

2 Approach

To measure the GHG emissions associated with each delivery method, we adopted an attributional life-cycle assessment (LCA) approach, consistent with that of the BBC White Paper and the DIMPACT project. We first mapped out each of the functional processes that take place to deliver TV content, then assigned variables and parameters to model the behaviour of TV delivery methods.

2.1 Methodology

To measure the GHG emissions associated with each delivery method, we:

(1) Developed detailed system maps of each of the delivery methods considered in the study, to understand the components that consume energy.

(2) Collected data on system variables and parameters that govern each component of the system, to undertake the quantitative modelling.

(3) Used viewership data to determine the overall emissions per device hour of TV content.

(4) Used this model to explore the carbon impacts under different conditions based on a set of plausible scenarios, with different model parameters (e.g. viewership, delivery method penetration).

2.2 Functional unit

This project sets out to measure the GHG emissions associated with the delivery of TV content across three different delivery methods. To compare the different methods, a common unit was required. For this study, we measured the GHG emissions associated with one device hour of television.

This is consistent with the functional unit used in other studies and media publications, such as the BBC White Paper, Netflix's public disclosures on streaming emissions[5], and various other studies that estimate the emissions of TV content.

For the scenarios analysis, we supplemented this functional unit with estimates of the total annual energy consumption and greenhouse gas emissions per country.

2.3 Study boundaries and limitations

2.3.1 Geographical

This study focused only on European countries. We used data from pan-European studies, combined with detailed country-level research where this was available. Countries with a high level of country-level data available – either provided by Project Sponsors or publicly available – included the following countries:

- Austria
- Croatia
- France
- Germany
- Spain
- Sweden
- United Kingdom

The countries chosen also varied in terms of prevalent delivery methods, geographical region and size, topography, population, and viewership behaviour. As such, they provided a sound subset to confirm that the modelling was applicable for different scenarios. We then expanded the modelling to all other EU28 countries. By convention,

[5] https://www.wired.com/story/netflix-binge-watching-carbon-footprint/

we designate by EU28 the European Union (27 countries) and UK. For the Scenarios, we only considered a pan EU28 view.

2.3.2 Technical

This study only considered the *downstream* emissions of the delivery of TV content, not the production of such content. In this section, we outline the detailed boundaries and limitations of the study.

2.3.2.1. Television sets

This study only considered viewing hours that took place on TV sets within private households.

We acknowledge that other types of consumer electronics devices such as smartphones and computers are also being used to access OTT (live or on-demand) services such as Netflix, Viaplay and Canal+. We focused initially on viewing hours on TV sets to compare typical DTT and managed IPTV viewing on a level playing field with OTT viewing. As at the time of writing this report, TV sets remain the most common devices to view broadcast and SVOD services across Europe, even for popular OTT services like Netflix[6].

Whist we only considered viewing hours on TV sets; we did not consider the energy consumption of the TV itself as part of the main modelling. This is because the primary objective of the study was to compare the GHG emissions of different TV *delivery* methods. Excluding the TV sets – assumed to be the same for each delivery method – enhanced this comparison. We did, however, include a standard TV set in some of the analysis, to compare the results of this study to others where the TV set was included.

We also assumed that where viewing takes place via a TV set without additional in-home peripheral devices (excluding modem/routers), there was no uplift of power consumption for the television set. This assumption is largely untested but is in line with approaches taken in similar studies (e.g. the BBC White Paper).

Further, there is some evidence suggesting that high dynamic range (HDR) functionality[7] in newer TV sets may have an impact on their energy consumption. For example, the EU Energy Labelling Regulations require that the energy efficiency of HDR is labelled separately to that when the television is in standard dynamic range (SDR) mode[8]. HDR encoding is a design decision by the organisations providing the content – for example a streaming platform or broadcaster – and it may be more common in some delivery methods than others. Whilst not considered in this study due to a limited amount of research into this topic, this may be worthy of future investigation.

2.3.2.2. Shared broadcast services

Shared broadcast services such as playout and encoding were not included in the study, as these were assumed to be shared amongst the delivery methods. As such, these processes would not drive differences in the energy consumption of the different methods. Furthermore, the BBC white paper identified that these are a small share of the overall footprint (<1%) and so can be ignored in line with the ISO14040 standard for Life Cycle Assessment.

2.3.2.3. Fixed versus mobile internet networks

As only viewing on television sets was considered, we only included viewing undertaken via fixed line networks.

2.3.2.4. Delivery methods excluded

This study did not consider a detailed analysis of cable and satellite television. Detailed analysis of these methods were excluded from the scope of this study, which focused on DTT on the one hand, and the growing delivery platforms of managed IPTV and OTT on the other. Cable is increasingly transitioning to IP delivery, and data is available in the context of UK in the BBC White Paper. Data on satellite reception is also available in the

[6] https://www.vox.com/2018/3/7/17094610/netflix-70-percent-tv-viewing-statistics
[7] https://www.whathifi.com/advice/hdr-tv-what-it-how-can-you-get-it
[8] Refer to Clause (10) of EU 2019/2013, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.315.01.0001.01.ENG&toc=OJ:L:2019:315:TOC

context of UK in the BBC White Paper[9]. These studies suggested that cable and satellite viewing had a similar energy intensity to IPTV.

However, satellite and cable viewing were considered where it was necessary to derive the viewing hours (refer to Section 3.1 below) for each of the in-scope delivery methods. We did not model the energy consumption of cable or satellite delivery.

For OTT modelling, we did not consider the viewing of internet video platforms beyond the Video on Demand (VOD) platforms in Europe such as Netflix, Amazon Prime and Salto, as well as public broadcasters' VOD services (e.g., BBC iPlayer). The study therefore excluded video sharing platforms such as YouTube and Vimeo.

2.3.3 GHG emissions data and renewable energy

Many organisations serving media entertainment – as well as those along the value chain – have set net-zero GHG emissions targets. This generally means that these organisations commit to reducing their energy consumption as much as practically possible, actively sourcing or generating renewable energy to reduce GHG emissions, then offsetting the remainder of emissions by purchasing offsets. Net-zero commitments and Science-Based Targets usually require organisations to also encourage companies in their value chain to reduce their emissions.

This suggests that over time, actual emissions from delivering TV content may decrease. However, given that this study does not use individual organisations as the unit of analysis, we must consider the fact that not all TV value chain participants have such aggressive efforts to reduce their GHG emissions. As such, we use national emissions factors to calculate energy consumption. These consider each country's overall energy mix, not the renewable energy consumption of significant value chain partners. This is aligned with the location-based emissions method of calculating GHG emissions from electricity consumption in the GHG Protocol's Scope 2 Guidance[10].

[9] We do note, however, that the carbon intensity of the electricity grid has changed since the BBC White Paper. Thus, we recommend only considering the energy consumption findings provided in this paper.
[10] https://ghgprotocol.org/scope_2_guidance

This approach allows us to understand the energy demands placed on the grid by TV viewing but has its limitations. For example, British Telecommunication's (BT) Openreach in the UK – the backbone for most of the internet infrastructure in the country – is run on 100% renewable energy[11]. This detail was not able to be captured and quantified in this study. It must be noted, however, that the core network component is not a significant driver of emissions, and thus is unlikely to have a significant impact on the study conclusions.

Emissions factors are one of the key variables in the modelling of different infrastructures, explaining in large the differences across geographies. These differences arise because of different power generation mixes in each country. Given its relevance, the model is built in a way that it can capture the intricacies of different stages. As our default scenario, we are considering the national grid emissions factor for each of the countries involved. The figures used were obtained from the European Energy Agency's "Greenhouse Gas Emission Intensity of Electricity Generation" update in November 2020, containing the values for 2019[12].

Our approach focuses on the consumption of the ultimately scarce resource, energy, regardless of how it is produced, and translates it into GHG through national factors. This may disregard specific efforts but provides the most neutral overview, also bearing in mind that a large part of the GHG originate from the home.

2.3.4 Attributional versus consequential GHG accounting

The modelling undertaken in this report is taken from an accounting perspective. That is, it looks at the energy consumption over a given period, then attributes that usage to the product or service of interest. In some cases, all emissions are attributed to the service (for example, the emissions of the terrestrial transmission network) but in other areas where the energy consumption was shared with other services (for example, internet infrastructure also transmits non-video data). For cases that fall under the latter, we must attribute a portion of the emissions from a service.

[11] https://www.bt.com/about/digital-impact-and-sustainability/tackling-climate-change
[12] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-6

This *attributional* approach is more commonly understood and used, and is the approach adopted in this study. Specific attribution approaches are outlined throughout in Section 3. For some areas, such as internet infrastructure, attribution to the service in question is completed using data volumes. Note that, to achieve energy balance in an attributional approach, a share of standby energy used when devices are idle (for example home Wi-Fi equipment at night) is allocated to services using that device.

However, at some point in the future (or a hypothetical scenario), a system may be scaled up or down to meet increasing or decreasing demand. The evaluation of the energy consumption and embodied emissions of this change is referred to as *consequential* life-cycle accounting. For the ICT sector, this method is less developed, as it requires a wider in-depth analysis of the drivers of such increase in demands (for example, increased video demand versus IoT devices and gaming). As such, it was beyond the scope of the study to provide a detailed view of how TV viewing via various delivery methods (managed IPTV and OTT) were causing an increase in demands of the internet network to the point where more infrastructure was required. This should be kept in mind especially when considering our analysis on future scenarios.

2.3.5 Scenario modelling

Our analysis of scenarios is of course fraught with uncertainty. Nobody knows what will happen with certainty into the medium term, let alone the long term. The baseline scenario presented in the report is developed generally based on extrapolation of current trends and – where available – published forecasts from reputable sources. The other scenarios explore the sensitivity to other possible evolutions. For modelling reason, the evolution profile for cable and satellite is kept identical across all scenarios to allow for a meaningful comparison of scenario results. It is important to note that our scenarios themselves aren't forecasts – they consider possible future situations, not the future that will necessarily happen.

2.4 Embodied emissions

Other studies, such as the BBC White Paper, that also measure the GHG emissions of television tend to focus on the use-phase consumption. That is, the emissions associated with the use of the equipment to deliver and view TV. Embodied emissions – those that arise from the raw material production, manufacturing, transport, and installation of devices – is either not considered or treated separately.

A key reason for this is the higher level of uncertainty of estimating embodied emissions when compared to use-phase energy. This is due to the wide array of devices with potentially significant variation in embodied emissions, uncertainty about how long a device is used for, and a lack of studies on the full lifecycle of such devices.

In this study, we conduct a brief analysis of embodied emissions based on the proportion of emissions. This is to provide some context on the scale of embodied emissions compared to the use phase. It should be noted that this is highly uncertain and based on somewhat dated, high-level estimates provided by the GHG Protocol ICT Sector Guidance. We recommend that individual organisations or countries conduct their own analysis on the typical devices used for their market and look to gather primary data on full life cycle emissions.

3 Delivery methods

This section describes each of the delivery methods considered in the analysis, and how we allocated TV viewership to each method.

3.1 Estimating viewership per delivery method

Estimating the viewership of TV across the different delivery methods was the first step taken to analyse the unit carbon impact of each method. This involved translating estimates of viewership hours and TV market penetration to estimate the device-hours for each delivery method.

3.1.1 Device-hours of linear and time-shifted delivery

To estimate the device hours of linear television (including time-shifted content that is recorded), we drew upon data from the European Audiovisual Observatory (EAO). The EAO publish an annual Yearbook that includes national estimates of average daily viewing hours per person, which was the data point that was used for the allocation. This data referred only to television that was watched either live or time-shifted (non-linear) on a TV set (i.e., not on a laptop, smartphone, or tablet).

Time-shifted content is viewed predominantly via a broadcaster's catch-up apps – delivered via the internet and thus the OTT delivery method. In some countries such as the UK, non-linear viewing may also be achieved by recording the content locally when broadcast and viewing later, using a personal video recorder (PVR). It was the view of the Project Sponsors that PVR viewing was not common in most European countries and will continue to become less prevalent as OTT apps increase in popularity.

[13] This includes those who also use other delivery methods

To estimate the usage of each of the linear delivery methods, we drew upon the primary market penetration data provided by various European sources (with the assistance of the Project Sponsors) to estimate the proportion of TV viewed via these delivery methods. One complication is that primary penetration does not consider the fact that some households had multiple viewing methods – mainly DTT combined with another delivery method (IPTV, cable, satellite).

To address this uncertainty, we adjusted the market penetration data based on the upper and lower estimates of DTT usage. We obtained upper and lower limits of the viewership by assuming for each country as defined by the following:

- **Upper limit**: The total number of households that use DTT[13].
- **Lower limit**: The number of households using only DTT to access TV.

The middle point between the lower and the upper limit values was used as an estimate of the total viewing via DTT. It is important to note that taking an average of the lower and upper limits was a simplifying assumption, and other weights could have been considered. However, given that this is mainly used to calculate broadcast infrastructure efficiency (energy/viewing hours) this was not expected to significantly impact the results, as the network distribution was only a small component of the overall result.

With this DTT viewership estimate together with the viewership share for other methods (Satellite, Cable, IPTV), we could calculate the proportion of the total viewership (out of 100%) to use when splitting the hours of TV content viewed in each country. This is outlined in Figure 1 on the following page.

This method had some limitations. For example, it did not explicitly consider secondary or tertiary television sets, which – in the case of France, for example – are more likely to be DTT even if the primary television set was IPTV[14]. It was expected that this was incorporated by using the average of the lower and upper limits of DTT penetration.

[14] Observatoire De L'Equipement Audiovisuel Des Foyers De France Metropolitaine 2020.

3.1.2 Combining BVOD and SVOD viewership for OTT estimate

The above method does not consider all device-hours viewed via OTT delivery that occurs on TV sets. The reason is that viewership measurement in most European countries do not include viewing that is never aired via linear TV. As such, it only can be used to estimate OTT device-hours from content viewed via broadcasters' catch-up apps – broadcast video on demand (BVOD), based on the current watermarking approaches used.

We estimated the viewership of BVOD based on the proportion of TV viewing that is time-shifted or non-linear, which is estimated by the EBU to be 90% across Europe[15].We also split this time-shifted viewing time between BVOD and content that was recorded by viewers and watched later. To do this, we drew upon estimates and experience from Project Sponsors to agree a split of time-shifted viewing that was recorded (and thus delivered via DTT, managed IPTV, cable, or satellite) versus BVOD.

Subscription video on demand (SVOD), is not generally included in the TV viewership estimates that are provided by current estimates. SVOD includes services such as Netflix and Amazon Prime. As SVOD continues to increase in penetration, this was an important component to attribute to the OTT delivery method. Hourly viewership data for SVOD is not readily available in any pan-European studies, however various country-level sources were available, such as from organisations such as Ofcom in the UK and CSA in France. Viewership per capita of SVOD (including non-viewers, so to be consistent with current TV audience measurement) are emerging and typically point to between 0.5 and one hour per day per person, depending on the source. This figure should not be confused with another one, number of hours per user, which applies only to the subpopulation of subscribers and is therefore higher.

3.1.3 Accounting for multiple viewers per device

We then needed to estimate shared viewership (more than one person viewing a television set) to calculate the number of hours *per device*. This is because the EAO provides viewing hours per person. To do this, we calculated the average shared viewership based on household size:

- 1.0 viewer per device for one-person households
- 1.5 viewers per device for two-person households
- 2.0 viewers per device for three + person households.

This was consistent with the methodology used in the BBC White Paper. Eurostat household data was used as a proxy where TV household data was not available[16].

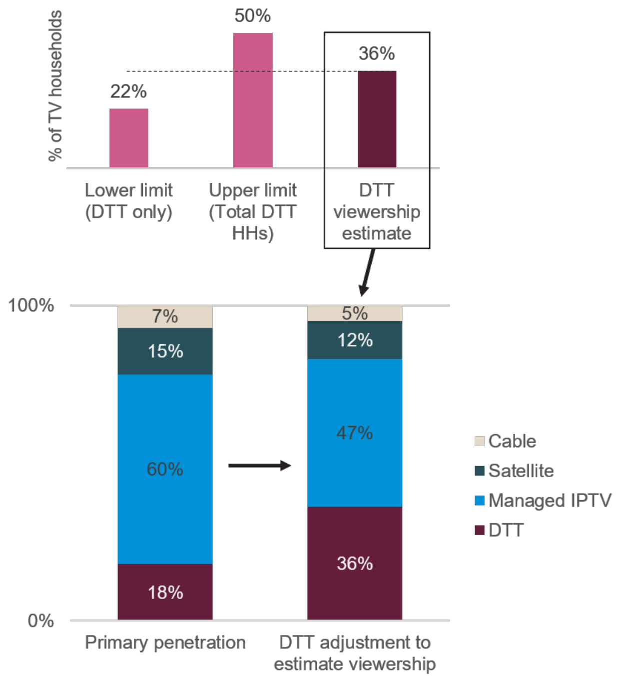


Figure 1. Estimating viewership of each delivery method

The approach we took to break down overall viewership data to each delivery method is summarised in Figure 2.

[15] EBU Audience Trends: Television (2020) https://www.ebu.ch/publications/research/membersonly/report/audience-trends-television

[16] https://ec.europa.eu/eurostat/web/lfs/data/database

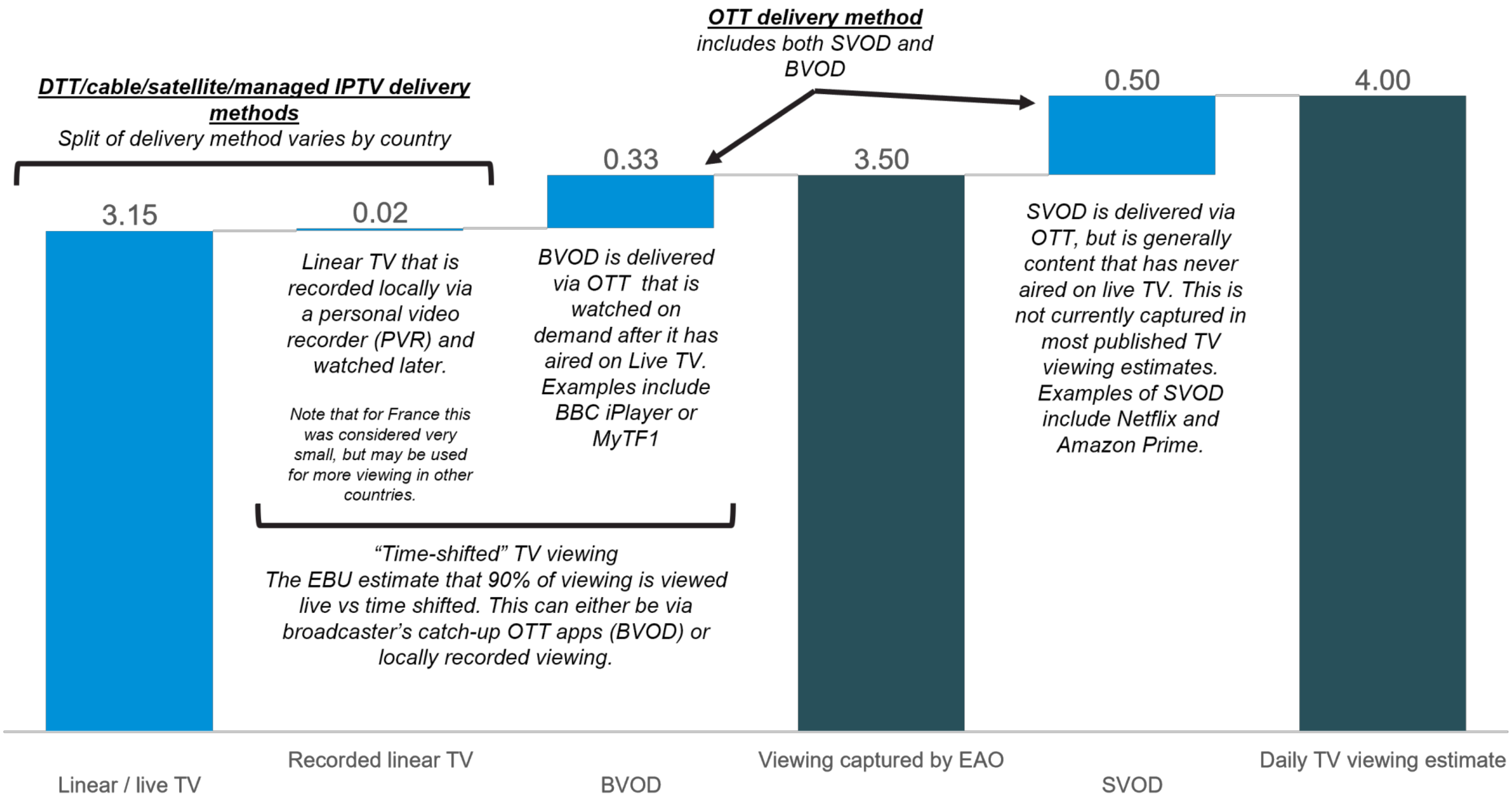


Figure 2. Summary of the method used to estimate total viewership and allocate viewership to different delivery methods. The example provided above is for France

3.2 Digital Terrestrial Television (DTT)

Figure 3 outlines the reference architecture model for DTT modelling, and this section explains the method used to model this system.

3.2.1 Terrestrial broadcast distribution infrastructure

DTT distribution consists of relaying the signal to a network of transmission stations geographically distributed over the service area. For a large country, there can be over one thousand transmission stations across the country, each with several transmitters. The signal of a TV channel is merged to create multiplexes, typically 5 to 10 channels per multiplex. The set of multiplexes defines the DTT bouquet (typically 20-50 programs) available in any given country.

Relaying is carried out by a dedicated high-performance distribution network carrying one or more multiplexes, each of which is associated with a specific transmitter connected to a specific or common antenna at each transmission station.

In Europe, transmitters are managed by private organisations – many of which are members of Broadcast Networks Europe – a Project Sponsor. As such, we were able to gather primary data from some of these operators. For countries where primary data was not available, a proxy value for the energy consumption was estimated based on primary data from other countries. To do this, three datapoints were estimated, scaling the energy consumed by the distribution infrastructure by three distinct metrics:

- Surface area (km^2)
- Total number of people
- Number of transmitters

For the first two proxy values (based on the surface area and on the number of people), the figure obtained was also adjusted by the ratio of number of multiplexes. The proxy obtained from the number of transmitters was taken directly, with the number of transmitters relating directly to the power usage. From the three datapoints obtained, the midpoint (average) between the maximum and the minimum was considered.

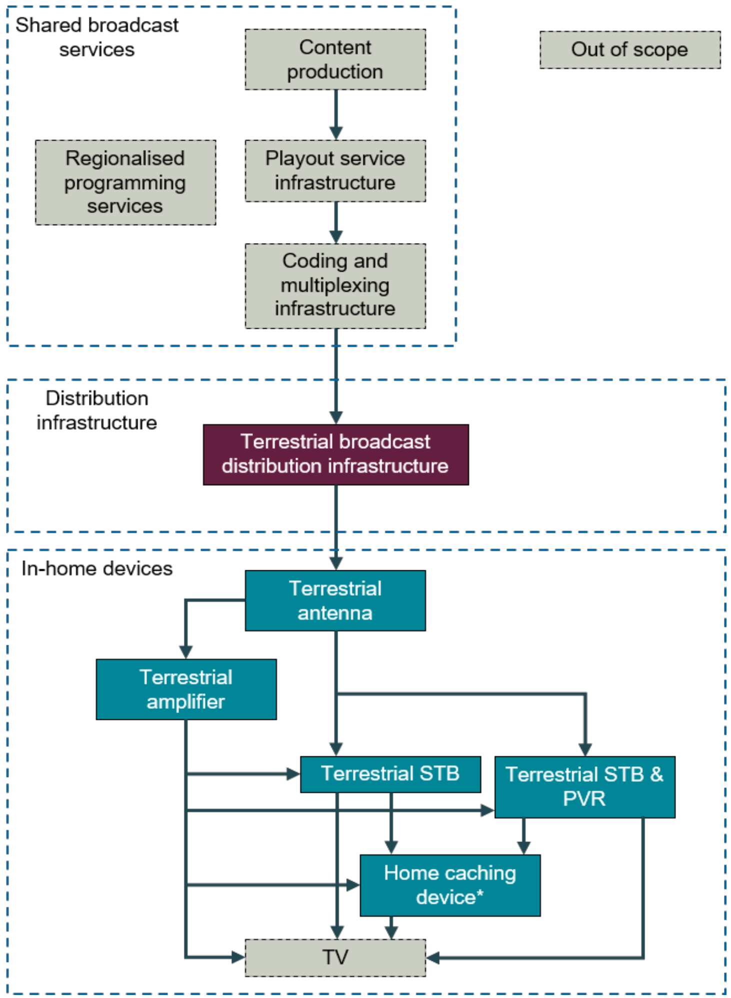


Figure 3. DTT reference architecture model (* home caching only included in some future scenarios)

With the aim of increasing the accuracy of this proxy value, the scaling factors were calculated taking all the primary data provided. Therefore, the scaling factors obtained were:

- Average kWh per transmitter
- Average kWh per person (adjusted by number of multiplexes)
- Average kWh per km^2 (adjusted by number of multiplexes)

3.2.2 DTT in-home devices

Currently, DTT generally requires a simple home networking set up. Signal is received in households via an antenna, which is then decoded either via a set top box (STB) or by the television.

3.2.2.1. DTT antennas and amplifiers

Typically, viewers receive the DTT signal from their own antenna. It was assumed that these antennas do not consume any power. In some cases, where signal is weak, or where signal is required to service multiple households (e.g., in apartment buildings) a powered antenna amplifier may be used.

Data on the proportions of households using antenna amplifiers, and their power consumption was not readily available. To align with previous work, we have adopted the estimated figure from the BBC White Paper. We have assumed that, in their use phase, amplifiers remain on at a constant rate, and this does not change whether the TV is on or off.

3.2.2.2. Set-top boxes (simple and complex)

In the past, DTT signal was decoded using a set top box (STB). Input from the Project Sponsors suggested that only a small minority of viewers may still require these, as television sets now offer this functionality. Thus, this form of STB was considered marginal in the analysis, except to account for markets where a technology transition is recent. Another exception to this assumption was Austria, where DTT content is encrypted. In this case, a simple STB is required to decrypt the content. We refer to this type of device as a *simple* set-top box.

However, viewers may still use a STB with a PVR to record and watch content after it is broadcast. In some cases, live TV may also be viewed via DTT using such STBs, as they may offer additional functionality such as integrating DTT and other delivery methods into the same user interface[17]. We refer to these devices as *complex* STB and are likely to have a higher energy consumption than simple STBs.

The prevalence of complex STBs may vary significantly between markets, and whilst recorded content is still quite common in the UK[18], it was the view of the Project Sponsors that this was not common in other European markets (published data on the proportions of households using such devices is difficult to come by across European countries). As such, this section is of little significance to these countries. However, for each country, we estimated the proportion of households with each set up (using a STB versus viewing without a STB) based on expert judgement from Project Sponsors, or country-specific reports where available.

We also modelled the power profile of complex STBs. It was assumed that these boxes had three power states, based on a simplified version of the Energy Star Power state model approach:

- On: Switched on and sending video and audio to the TV. It was also assumed that a STB was in the ‘on’ state is any recording was taking place.
- Active standby: This mode generally consumes only marginally less power than the ‘on’ state, as it allows a quick start up when switched on. This is consistent with the findings of Urban et al (2017)[19].

[17] For example, YouView in the UK integrates DTT and managed IPTV, and OTT apps within the same user interface.
[18] Ampere Analysis (2019), *The UK VoD Market*, refer to Graph 3.1.3 on p24, https://www.ofcom.org.uk/__data/assets/pdf_file/0026/149075/ampere-analysis-current-status-future-development.pdf

[19] https://www.researchgate.net/publication/335911295_Residential_Consumer_Electronics_Energy_Consumption_in_the_United_States_in_2017

- Passive standby: A standby mode with a much lower power draw. As per the voluntary agreement, STBs are required to have an Automatic Power Down feature, which should be defaulted to 'on'.

A fourth state could be completely switched off. However, it was assumed that in the use phase of their life cycle, STBs were at least on passive standby. This assumption was further justified by the low 'passive standby' state of STBs.

Complex STBs have the option to record content when the television is switched off, to be consumed at a later date. For this viewing case, the power consumption during recording was added to energy consumption of the viewing. We also applied an additional uplift of 10% for content that is recorded but never watched. This latter approach was consistent with approach adopted in the BBC White Paper.

Complex STBs often have advanced functionality that allows multiple types of TV to be routed through them. For example, some channels may be provided by DTT signal, whilst others may be via managed IPTV, with the option to view OTT via integrated apps within the STB. As such, all standby power cannot be allocated to the viewing of DTT. The standby power was thus allocated accordingly, based on market penetration of viewing devices.

3.2.2.3. Direct to TV

Many households view DTT by connecting their antenna cable directly into the television. It was assumed that, where this was the case, the power consumption of the television did not increase significantly to de-code the signal. As such, this setup was modelled to have no additional power consumption, when compared to those with a STB.

3.2.2.4. Home caching devices

Home caching devices are a technology that is being considered as a way to utilise DTT networks for delivery of VOD content. This would involve receiving content via DTT signal, cataloguing, and storing content locally. This may be integrated through initiatives such as HbbTV[20]. For a summary of home caching, which is only considered in the scenarios analysis, please refer to Section 4.2.8.

[20] https://www.hbbtv.org/

3.3 OTT

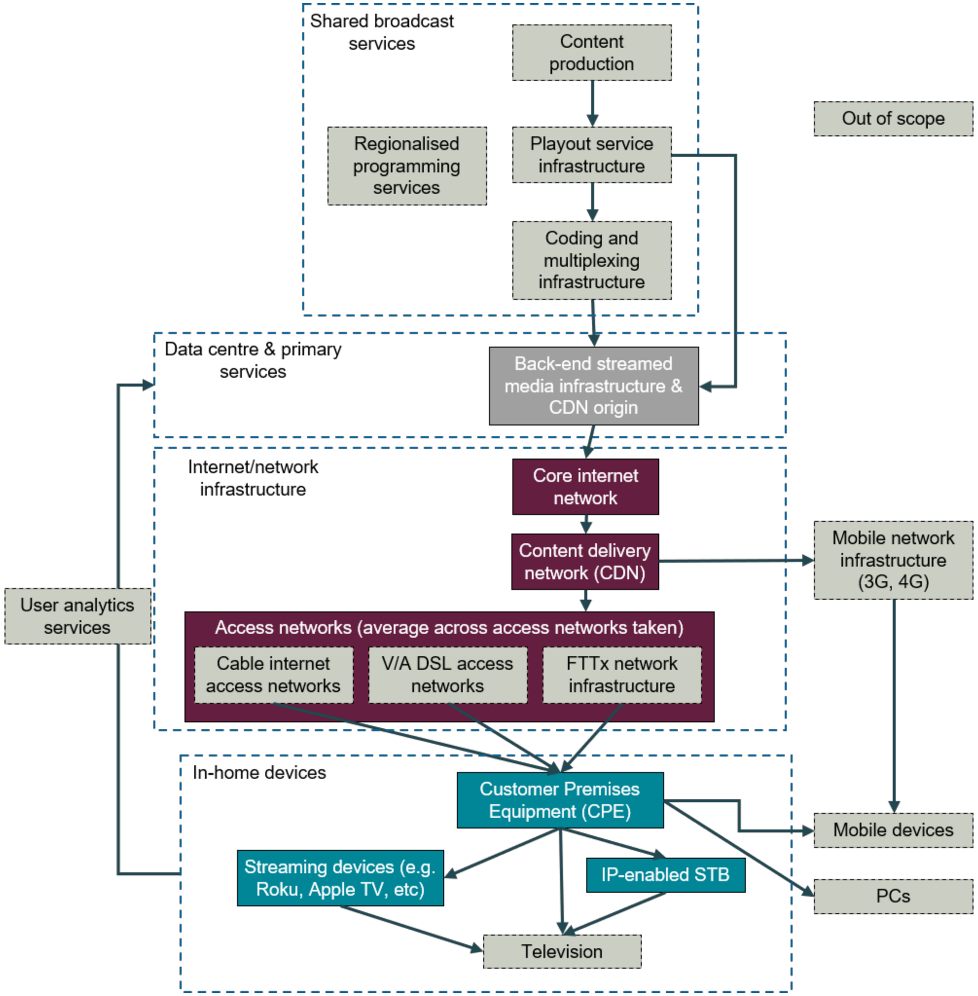


Figure 4. OTT reference architecture model

Over-the-top (OTT) delivery is where content is accessed via an internet app (such as Salto or All4). OTT distribution occurs via unicast IP packet switching, meaning that individual streams of data are transferred each time a viewer requests to watch television.

OTT allows for users to watch live/linear TV channels, or video on demand (VOD). Currently the modelling completed is not so granular that we can measure the difference between live and on-demand viewing via OTT delivery – it is assumed that all OTT is delivered via unicast. Multicast is only considered in the case of managed IPTV.

Figure 4 outlines the functional components of the OTT delivery of content, and the remainder of this chapter outlines how we approached the modelling of these devices.

3.3.1 Data centres and CDN origin

OTT content is stored in data centres, either on-premises or cloud infrastructure, and is distributed to content delivery networks via a CDN origin server. Given that different organisations may more commonly serve content from CDN data centre, with unique storage volumes and levels of replications, there was uncertainty about how to derive the energy consumption for a general case.

We were able to draw upon some indicative results averaged across DIMPACT participants. As such we assumed that the average energy consumption per viewing hour was 1.3Wh/hr. This figure has also been published in a White Paper by the Carbon Trust[21].

3.3.2 Content delivery networks

Content delivery networks (CDNs) are data centres located closer to the end users than the original content. CDNs store copies of the media content. A significant proportion of internet content is delivered via CDNs[22], and their use is even more pervasive amongst mainstream OTT providers.

[21] Carbon Trust (2021), Carbon impact of video streaming - white paper (forthcoming)

[22] https://blogs.cisco.com/sp/cdn-caching-and-video-streaming-performance

Therefore, as a conservative assumption, we have assumed that 100% of OTT content is delivered via content delivery networks.

The most common way to model the emissions from CDNs is to apply an energy consumption figure per GB of data used. Estimates of this vary but are within the ranges of 0.04Wh/GB and 1Wh/GB. For this project, we used a factor of 0.1Wh/GB, which is consistent with that used in the DIMPACT project. An explicit sensitivity analysis was not completed for this study, because the results showed that this is a minor component of the overall energy consumption of the system.

3.3.3 Internet infrastructure

Content is sent from back-end streamed media infrastructure and CDN origin via the core internet network. Data packets are then transferred from the CDN to the user via local access networks. We know that the energy consumption varies by local access networks (DSL, Full Fibre, Cable), however, reliable data on the different power consumption of these networks was not available at the time of writing. As such, we used average values across the access networks to simplify the modelling.

We estimated the energy consumption of the internet infrastructure that video streaming is responsible for by allocating via data volume. To do this, we estimated the energy consumption per subscriber line (using published watts per line data) and divided this by the average data volume per subscriber line. This data was available from the Ofcom International Broadband Scorecard[23]. Where data was not available for certain countries, we used data from country-level sources where available or made estimates based on similar countries (or averages of countries) in the region. We could then use the energy intensity (kWh/GB) figure to estimate the energy consumption of one hour of TV content delivery via IP networks.

Based on our conversations with internet service providers, as well as a quick sense check, we realised that the data volumes for multicast IPTV delivery was not included within the published Ofcom estimates. This may explain why data volumes per capita for the UK (low multicast IPTV penetration) were significantly higher than for France (high IPTV penetration).

This can be demonstrated in the case of France. For France in 2020, we assumed a data volume of 52.1GB/person by applying an increase of 22% to convert Ofcom's 2019 estimate of 42.7 GB/household. We also estimated a viewership of multicast IPTV of 1.27 hours/person, per day. Using a bitrate of 5Mbps we see that the total daily data volume from IPTV alone is 86.82GB/person, which is higher than the Ofcom figure. This suggests that data volumes for multicast IPTV are not included, and thus needed to be added. In France, the calculation implies that OTT accounted for 27% of household data consumption. As OTT increases in usage, we would expect this to rise in future years.

As such, we used the estimated linear IPTV distribution per country to increase the data volumes per household to include multicast IPTV data. We then used this total data consumption to allocate the energy of an hour of TV viewing.

We adopted this approach, as opposed to the published kWh/GB figures summarised by Aslan[24] for several reasons. First, this allowed us to remove the core network component when modelling the IPTV network (where core energy was assumed to be negligible, refer to Section 3.4.3) and adopt a consistent approach between the OTT and managed IPTV modelling.

Second, it is suggested that whilst demand for data is increasing, the energy consumption of internet networks has remained relatively stable[25]. As such, it makes sense to model based on energy consumption, then allocate the relevant portion to video by data volume. This allowed us to model the increase in data demand in future scenarios.

Finally, this allows for us to estimate differences in the energy intensity of the internet infrastructure in different countries, which has not been considered in other studies. We have assumed that IP infrastructure in all countries has a similar energy per subscriber, despite differences in data consumption.

[23] https://www.ofcom.org.uk/research-and-data/telecoms-research/broadband-research/eu-bbroadand-scorecard/international-broadband-scorecard-2020-interactive-data
[24] https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.12630
[25] See IEA (2020), Data Centres and Data Transmission Networks, https://www.iea.org/reports/data-centres-and-data-transmission-networks

Table 1. Applying an uplift of household data consumption to include multicast IPTV, and the resultant energy intensity of the IP network (core and access)

Country	Network energy	Monthly data use per capita (Ofcom)	IPTV multicast data volume	Adjusted monthly data use per capita	Estimated network intensity (kWh/GB)
UK	5.0W (Access)[26] 0.0051 kWh/GB (core)[27]	153.4 GB	14.9 GB	**168.3 GB**	**0.015**
France		52.1 GB	96.4 GB	**148.5 GB**	**0.017**
Austria		62.2 GB	18.5 GB	**80.7 GB**	**0.027**
Sweden		83.7 GB	30.3 GB	**113.9 GB**	**0.020**
Spain		56.6 GB	40.0 GB	**96.6 GB**	**0.020**
Germany		64.7 GB	17.3 GB	**82.0 GB**	**0.029**
Croatia		60.0 GB	50.5 GB	**110.5 GB**	**0.018**
Italy		48.7 GB	1.7 GB	**50.3 GB**	**0.038**
EU28[28]		61.4 GB	32.0 GB	**93.4 GB**	**0.021**

When compared to the estimated network intensity provided by Aslan's regression analysis for 2020 of 0.0065, as cited by the Carbon Trust in their recent white paper, we can see that the intensity figures used in this study are slightly higher. However, this is lower than the figures provided elsewhere, such as Andrae (2020)[29] This gives a conservative estimate, and provides an analysis of the variation in intensities between countries. We welcome any primary data from internet service providers that could confirm or refute these estimates.

This method, as well as emerging research[30] suggests that the power consumption of internet infrastructure and customer premises equipment may not change significantly between a passive state and when a high data volume is travelling through the network. This equipment is always on to meet spikes in demand, and thus will be on regardless of data consumption. This was observed by telecom operators during the coronavirus pandemic, where an increase in data traffic led to no, or negligible, increases in energy consumption across their networks[31]. This implies that changing the bitrate (say, from HD to SD) would not instantaneously affect the energy consumption of the network. As such, an alternative approach would be to estimate emissions based on time that a service is used, as opposed to data volumes. However, as this method was still emerging, we did not consider it in this study.

3.3.4 Customer premises equipment

Customer premises equipment (CPE) is generally the modem/router inside homes. We have excluded peripherals such as Wi-Fi extenders in this analysis. Modem routers tend to consume power regardless of whether TV viewing (or other internet usage) is occurring and are typically on 24 hours per day. As such, we adopted the same allocation approach for modelling the CPE as the other components of the IP networks. In our modelling, this was included within the network, and is outlined as part of the summary in Table 1.

3.3.5 IP-enabled STBs and streaming devices

Viewers can either watch OTT television by connecting an IP-enabled STB, streaming device, or gaming console, or simply by connecting to the internet on their IP-enabled television. If an IP-enabled STB, gaming console, or streaming device is used, these will consume additional power.

To model these peripherals, we made the following assumptions:

[26] Sourced from Table 3 of Malmodin (2020), *The power consumption of mobile and fixed network data services,* https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf, p87
[27] For the core component, we took the 9e-6 j/b result for 2016 from Krug et al (cited in BBC white paper). and converted to get 0.020 kWh/GB. We then applied a -29% CAGR (based on Aslan's regression analysis to 2020 to give us 0.0051 kWh/GB.
[28] Calculated using a weighted average of European countries.

[29] Refer to Table 7: https://www.researchgate.net/publication/342643762_New_perspectives_on_internet_electricity_use_in_2030
[30] https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf#page=87
[31] https://www.gsma.com/newsroom/press-release/covid-19-network-traffic-surge-isnt-impacting-environment-confirm-telecom-operators/

- IP-enabled STBs had the same power consumption and standby behaviour as the complex STBs outlined in section 3.2.2.2.
- Where OTT was viewed directly onto a television, we assumed that there was no uplift of power consumption of the TV when compared to other methods.
- Streaming devices (e.g., Roku, Apple TV, Chromecast) tended to be smaller, more basic devices that consumed less energy. As a conservative estimate, we assumed an upper bound based on an Apple TV device.

Data from the Ofcom's Media Nations Report 2020 allowed us to understand how consumers were viewing OTT services[32]. Unless otherwise stated due to country-specific data sources, we assumed that there was a similar viewing behaviour across Europe.

3.3.6 Data volumes

To understand the data flows through the networks, we needed to understand the data required to view one hour of TV content. Netflix provide a summary of their average bitrates across different countries and internet service providers in their ISP Speed Index[33]. We adopted these bitrates at the country level. For example, for Austria and France, this was 3.1Mbps whereas for the UK it was 3.6Mbps. It is expected that this average bitrate will increase as OTT providers increase the availability of HD and UHD. This increase in bitrate will be incorporated into the modelling for the short, medium, and long-term projections.

We were able to estimate the GHG emissions from the OTT module for a single hour of viewing (unlike the DTT module where an estimate of total device viewing hours was needed to average the network infrastructure). Thus, the total viewing hours per day was not required. However, this will be required for the scenarios modelling. In addition, the viewership information published by the EAO (via Glance/Mediamétrie) did not include the hours of OTT content viewed[34].

[32] https://www.ofcom.org.uk/research-and-data/tv-radio-and-on-demand/media-nations-reports/media-nations-2020
[33] https://ispspeedindex.netflix.net/global/
[34] Email communications with Glance representative, 31st March 2021

However, evidence suggests that most of the VOD viewing is still done on a television. For example, public analysis from Netflix found that 70% of global viewing occurred on a television set. In this first phase of the project, we only considered viewing that was completed on a television, not viewing on other devices such as mobile phones, computers, and tablets.

3.4 Managed IPTV

Current managed IPTV offerings in Europe tend to be provided by internet service providers (ISPs) and utilise their IP networks to deliver television content to end users. This delivery method has many similarities to the OTT delivery method, except that unlike unicast, data is routed through IP core networks only once. This is referred to as multicast IPTV and is unique to linear managed IPTV, as one data stream reaches multiple users[35].

Multicasting is achieved by routing the data through the IP network as users request IPTV channels. If some branches of the network do not have any users requesting specific channels, then this data is not sent along that branch. As such only the channel in the appropriate encoding for the requesting device is sent via the access network to the user's home, and if nobody is watching, no IPTV data is sent to the home. As such, this 'last mile' delivery of managed IPTV behaves similarly to unicast OTT.

Managed IPTV multicast can only be viewed for linear television, not on-demand viewing[36] or OTT services. The reason for this is two-fold. Firstly, the one-to-many delivery method would make it difficult to efficiently deliver on-demand services using multicast. Secondly, IPTV content is given some 'priority' within the network to ensure a consistent quality of service to viewers[37], as multicast does not benefit from the adaptive bitrate features of OTT. To do this requires an exemption from EU net neutrality regulations, which does not extend to non-linear TV content.

[35] Unless there is only one viewer of a particular channel at a given time
[36] With the exception of any locally recorded content via a PVR, which is still relatively common in markets such as the UK.
[37] From an interview with a French IPTV provider.

3.4.1 Back-end infrastructure and multicast servers

It assumed that a similar amount of energy consumption was required by servers to deliver and store the content for managed IPTV networks as OTT. This is outlined in Section 3.3.1. This is likely to be a conservative assumption, as this treats the servers as providing content to each individual customer, whereas in reality content is served from the headend only once. However, given this part of the system has a lower relative energy consumption to the networking, CPE and STB consumption, variation is unlikely to have a material impact on the results.

3.4.2 Content delivery networks

We did not include energy consumption from content delivery networks, as any content that is cached in the network is not a component in the linear multicast IPTV (but may be used for on-demand delivery, which is included in the OTT modelling).

3.4.3 IPTV network infrastructure

Any particular encoding of a linear IPTV is distributed via IP core networks only once, regardless of the viewership of each channel. This leads to increased efficiencies in the core network, especially when viewership of a channel is high.

Overall, the proportion of network traffic required for managed IPTV at any given time is relatively low compared to the overall data volumes transmitted via internet networks. In France, for example, an ISP may distribute over 500 channels at different bitrates and types of encoding which may sum to approximately 10-20Gbps[38] that is sent from the ISP headend. The total data served by the core network at any given time may be between 5-10Tbps[39]. This amounts to approximately 0.1% to 0.4% of the core network being used for managed IPTV. This proportion is then divided by a large number of viewers. As such, the core network is excluded from the IPTV modelling as a simplifying assumption.

However, managed IPTV still uses the internet access networks to deliver content to homes. This component of the internet access network is reported to have a higher power consumption than the core and metro network. When users request specific channels, a signal is sent upstream to request that the channel should be routed along that branch of the network, then sent via the access network to the viewer. With regards to this process itself, it was assumed that this additional routing computation was minor relative to the overall network footprint, and thus excluded from this analysis.

[38] Figures based on approximate figures provided during an interview with an ISP.

[39] See, for example, p7 of BT's 2021 Annual Review, https://www.bt.com/bt-plc/assets/documents/investors/financial-reporting-and-news/annual-reports/2021/bt-annual-report.pdf (Accessed 01 June 2021)

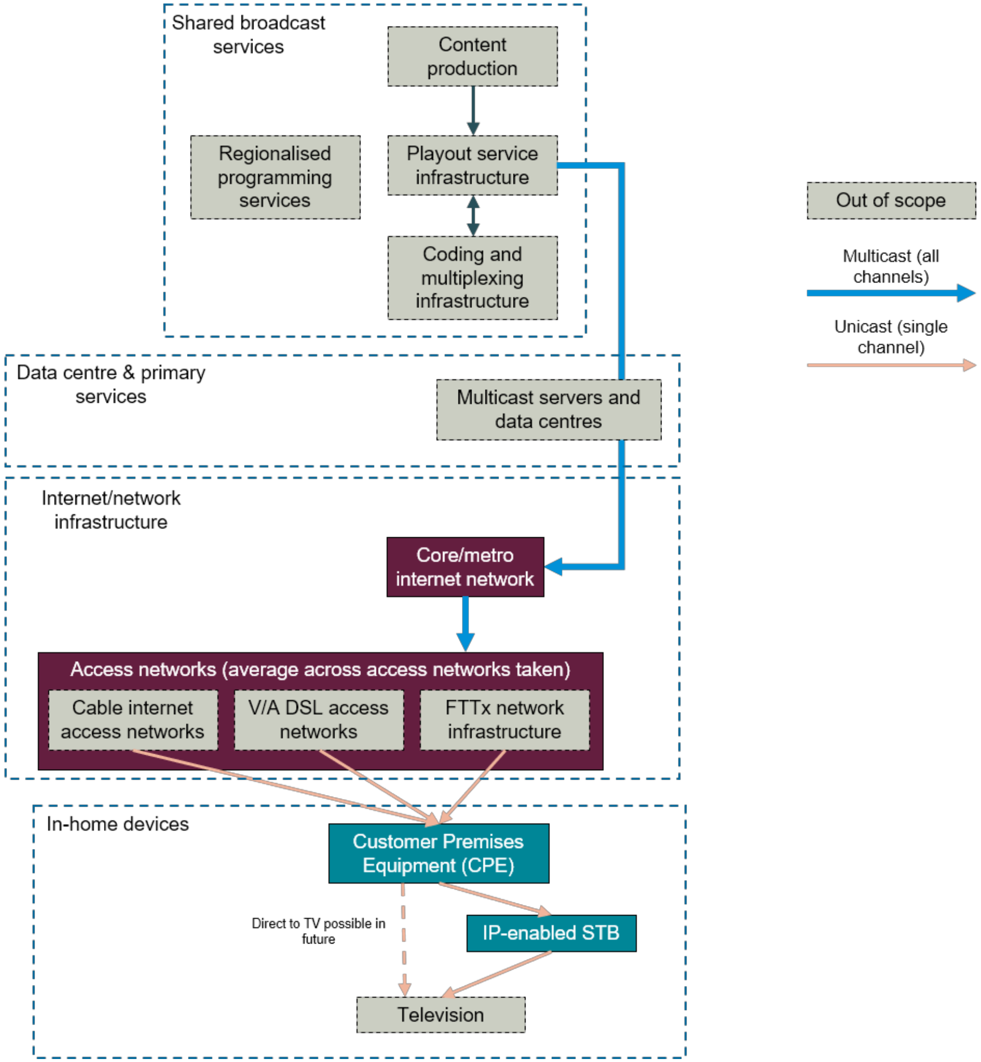


Figure 5. Managed IPTV Reference Architecture Model

From the local access network, the delivery to a viewer is similar to OTT. A single stream of data is sent to the viewer (not all channels served by the IPTV provider). As such, we allocate the power consumption of the access network in the same way that we allocated for OTT – by using the total data volume of IPTV data, divided by the total data sent via the line.

3.4.4 Customer premises equipment

Customer premises equipment is modelled in the same way as for OTT, outlined in Section 3.3.4. However, like the access networks, we use a higher average data figure to allocate CPE power, given that IPTV households are likely to have a larger amount of data flowing through their modem/routers.

3.4.5 IPTV STBs

For this study, we assumed that all managed IPTV requires customer premises equipment (e.g., modem/router) to interface with the IP networks, then a STB to decode the content for viewing on a TV set. This is another differentiator to OTT, which can be viewed on a wider range of devices. This may change in the future as this decoding functionality may be able to be in-built into televisions in future scenarios.

Beyond their functionality as a content decoder, set-top boxes are an important component of the managed IPTV system, both from a product offering perspective, as well as an energy perspective. Firstly, they are used by service providers to bundle other offers such as SVOD subscriptions and transactional video on demand platforms, and may potentially integrate other delivery methods such as DTT into the set-top boxes user interface. For example, pay TV channels might be delivered via managed IPTV, but public-service broadcast may be delivered via DTT, with native apps in the STB able to access OTT apps such as Netflix and Salto.

Due to this increased functionality, we modelled these set-top boxes as complex STBs, as outlined in Section 3.2.2.2. This means that IPTV STBs typically have a high energy consumption, with potentially a higher active standby power. Active standby power consumption is then allocated to IPTV based on the number of hours of TV watched on a device, and also takes into consideration that the complex STB may also be used for OTT viewing as well, to attribute only a portion of the standby time to managed IPTV.

Service providers in different countries will likely have different offerings, so a detailed look at STB emissions in different countries may be an area for future exploration at the country-level.

4 Scenarios

The future of television delivery is uncertain, and the industry is undergoing disruption, as we observe an increase in fragmentation due to changing viewing behaviour and a proliferation of OTT and IPTV offerings. At the same time, TV viewing habits and DTT platform are very resilient. In this section, we outline a series of scenarios that possible future TV trends may shift in different directions, with the caveat that these are essentially thought experiments and should not be considered a forecast of what is going to happen. These scenarios are used to estimate future energy consumption of TV delivery for Europe in the short, medium, and long term, but should not be taken as a forecast.

Table 2 provides a summary of the scenarios considered in the study. For each scenario, we needed to develop a new set of parameters to run through the model, to take into account the different trends. It was not simply a matter of multiplying the unit energy consumption calculated in the baseline scenario by the updated viewing hours, given the dynamics and assumptions of our life cycle modelling approach.

It is important to note that these scenarios should not be considered as forecasts about what will happen, but merely a different set of modelling parameters that aim to provide an indication of what could happen in the future, and the indicative impacts on energy consumption.

A full outline of the detailed scenario parameters for each country modelled is provided in Annex B.

Table 2. Summary of scenarios

Scenario		Description
A	Baseline IPTV growth (based on current trends)	For this scenario, we have analysed the recent historical trends in viewership behaviour and TV delivery penetration and some forecasts to assess how – if these trends continue –energy consumption and GHG emissions will be affected. The baseline accounts for growth of IPTV and OTT along with the roll out of very high broadband, growth of non-linear usage, growth of SVOD, growth of data usage and improvement in internet energy efficiency.
B	Increased rate of IPTV growth	This scenario evaluates a future where IPTV growth increases, and DTT penetration declines at a greater rate than in scenario A. It assumes that this decline will be displaced with IPTV and OTT.
C	IPTV plateau and regrowth of DTT	This scenario looks at the impacts if DTT was to stabilise then increase its penetration from 2025, as seems to be the case for instance in the USA. This plateau would be replaced by DTT, which may come about due to an increase of
D	DTT home caching for VOD	The final scenario looks at the possible impact of a speculative home caching model. Where DTT transmission is used in off-peak times to pre-load VOD content. This scenario examines how this method could reduce the amount of VOD content delivered via OTT. Refer to Section 4.2.8 for a full description of this scenario.

4.1 Countries modelled

With scenarios more uncertain than the baseline modelling, we relied more heavily on the judgement of the Project Sponsors in developing the modelling parameters. As such, we did not extensively model all 28 countries in this phase of the project and focused on the countries where there was detailed knowledge within the consortium. We focused on the EU28 estimate, which provides a pan-European view.

4.2 Description of key scenario parameters

Many of the parameters that we changed remained constant between the scenarios. This allowed us to isolate the impacts of certain shifts in TV delivery method penetration into the future – which changed significantly between scenarios to understand the carbon impacts. As such, many of the parameters that were adjusted (as discussed in this section) do not warrant discussion for each individual scenario, as they remain the same. This section outlines our approach to determining such scenario parameters.

We consider possible changes in the following areas:

- Demographics
- GHG intensity of energy consumption
- TV viewing trends and delivery method penetration
- DTT networks and interface
- IP networking and data consumption
- OTT and IPTV viewing methods
- Impacts of home caching (Scenario E only)

[40] Eurostat Population and Demography Database: https://ec.europa.eu/eurostat/web/population-demography/demography-population-stock-balance/database

4.2.1 Demographics

Total viewership is a function of population. A growing population is more likely to view more television. As such, we used population growth projections from Eurostat[40] to model population growth in Europe.

Whilst the EBU found that different age groups tended to have differing viewership behaviour, we did not explicitly consider how any change in age groups in the population when modelling viewership behaviour. We assumed that this was captured via the broader viewership trends.

4.2.2 GHG emission intensity of electricity consumption

European governments are setting targets to reach net-zero emissions before 2050, and lower-carbon electricity is a clear requirement to achieve this. Thus, in our future scenarios we considered the fact that the carbon intensity of electricity generation would reduce significantly. We used European Environment Agency (EEA)[41] projections to understand the overall reduction at the pan-European level. The EEA provide upper and lower indications. For our calculations, we took an average of these.

[41] EEA https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-8#tab-googlechartid_googlechartid_googlechartid_googlechartid_chart_11111

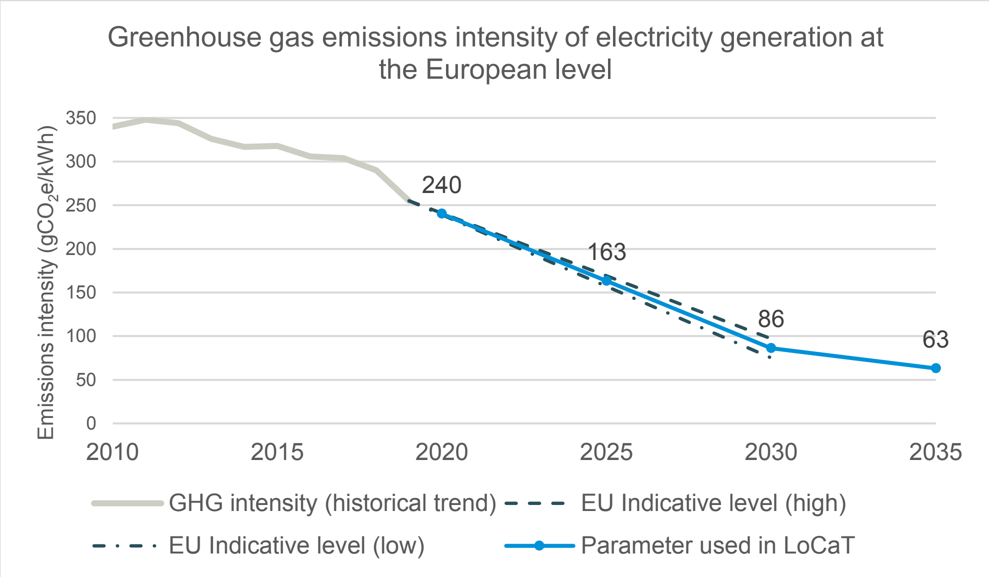


Figure 6. EU-level estimates of electricity grid intensity, and estimates used in LoCaT (Source: EEA)

For the individual countries that were modelled in the scenarios, we estimated the reduction based on these projections, and the level of decarbonisation that has already occurred in that country, to take into account the fact that those countries with a lower-carbon grid currently are less likely to further reduce their grid emissions factor as drastically as those with a higher dependence on fossil fuels. These estimates were overridden in cases where this was country-level forecasts available.

4.2.3 TV viewing trends and delivery method penetration

4.2.3.1. Linear TV delivery method penetration

TV delivery penetration was a key driving parameter in each of the scenarios, and the parameters that changed the most between scenarios.

We did not have detailed data on the forecast of TV penetration at the country level, except for expert input from the Project Sponsors in the short-term and the use of historical trends. Thus, for Scenario A we assumed that overall changes in TV viewing would follow historical trends. In addition, our estimates for 2020 assumed that live viewing via OTT on the TV set was negligible. However, based on the global trend of cord-cutting, we estimate that OTT will make up part of the linear TV viewing mix in the future. We have assumed a modest increase in most cases, with a higher proportion of viewing in the Scenarios with a more significant decrease in viewing using DTT.

For the other scenarios, we changed these trends to fit the description of the scenario, with the Project Sponsors providing their judgement on what constituted plausible potential futures in the other scenarios. A full outline of the changing viewing trends are included in Annex B.

Figure 7 provides an example for Scenario A at the EU level. Please note that non-linear VOD viewing is excluded from these charts but is included in the overall modelling. Each of the scenario charts was reviewed and agreed upon with the Project Sponsors.

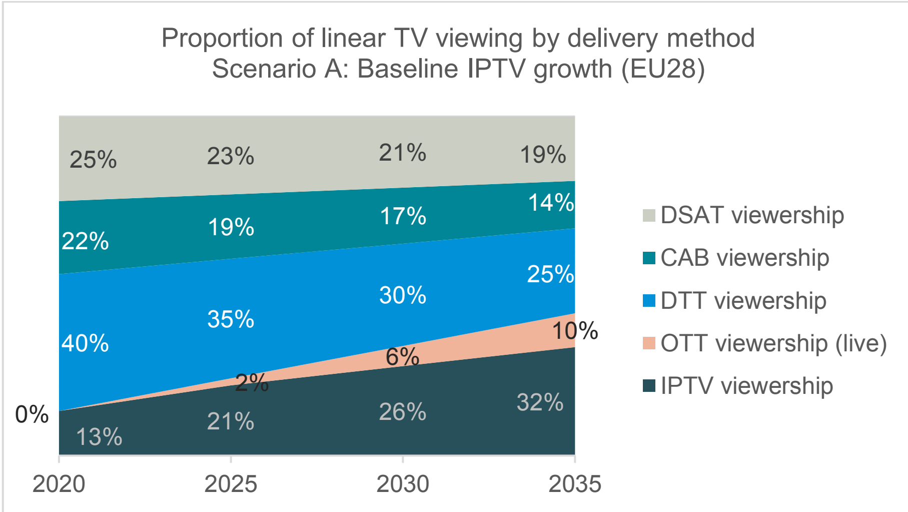


Figure 7. Estimate of changing linear TV delivery method for Europe

It is important to note that we held the change in cable and satellite viewing constant in each scenario (i.e., for all scenarios, cable and satellite % changes would occur at the same rate). This was to enable a comparison between the different scenarios in terms of a total combined energy of IPTV, OTT and DTT.

4.2.3.2. Proportion of time-shifted viewership

The EBU has seen a consistent trend in the viewing of time-shifted content reducing over the past several years. In our modelling, we assumed a decrease of 5 percentage points per 5 year. We assumed that this continued through to 2035, such that by 2035, 75% of TV viewing was live. This was expected to be replaced by viewing of time-shifted content via OTT platforms.

4.2.3.3. Total viewing time of linear, time-shifted and VOD

Based on reported EBU past trends, we took as baseline that TV viewing time excluding SVOD would continue to decrease at a rate of 4% every 5 years.

As mentioned earlier, there is a lack of data on total SVOD viewing time at the European scale today, as well as any forecasted data. Based on sponsors input we took as baseline that SVOD time would approximately double over the period to 2035, reaching for the European average about the level of the most advanced markets today in that respect.

This combined with the increase in BVOD resulted in a significant VOD time increase over the period, and in total a small increase of total viewing time on TV sets.

4.2.4 DTT networks and interface

It was the view of the project group that the modelling should assume that there would be no significant change in the energy consumption of DTT networks. This may be considered a conservative estimate, as improvement on transmitter technology and industry efforts may increase the efficiency of these networks. We also assumed that the proportion of households requiring antenna amplifiers would remain constant.

[42] See, for example, https://www.news.ucsb.edu/2021/020343/internet-energy-analysis-pitfalls

4.2.5 IP networking and data consumption

Researchers specialising in the energy consumption of data centres have outlined the challenges of projecting data volumes and corresponding energy consumption too far into the future, where changes can be rapid and unpredictable[42]. This is driven by a complex system of changing behaviour, technological development, and policy decisions – understanding this for the sake of our estimates is beyond the scope of this study. In the scenario analysis, we considered two key drivers for our modelling.

- Change in energy consumption of IP networks per subscriber line (to understand the energy consumption of the internet per household).
- Change in volumes of household data consumption (to be used to allocate energy consumption for OTT and managed IPTV).

4.2.5.1. Change in energy consumption of IP networks per subscriber line

Studies[43] have suggested that energy consumption of internet networks and data centres have remained relatively flat, despite dramatic increases in data consumption. This is due to the increase in data consumption corresponding with an increase in the efficiencies of the data centres and networks as infrastructure is upgraded. Whilst networks may continue to grow, consuming more power, but this is paired with an increasing number of broadband subscribers.

As such we assumed that the energy consumption of the networks per subscriber line remained stable. This is in line with the study outlined in Figure 8, which found that energy consumption per user of the entire ICT sector was decreasing to 2015, with an expected approximate flattening out thereafter.

[43] IEA, Global trends in internet traffic, data centre workloads and data centre energy use, 2015-2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-trends-in-internet-traffic-data-centre-workloads-and-data-centre-energy-use-2015-2021

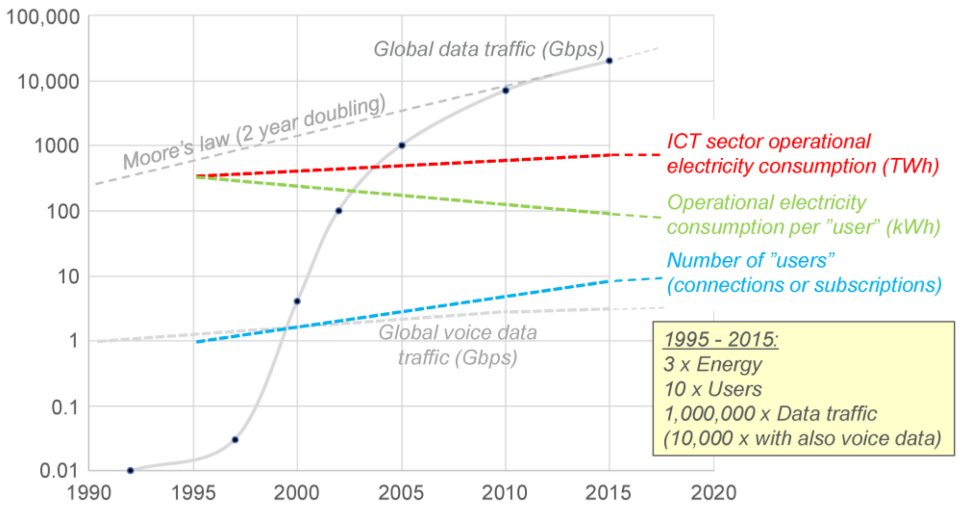


Figure 8. Total data traffic, operational electricity consumption, and number of users of the ICT sector 1990 to 2020 (Source: Malmodin and Lunden)[44]

4.2.5.2. Household data consumption

It is clear is that there is an explosion of IP data consumption within households across all markets. This is driven in part by increases in video streaming quantity and quality, but also online gaming, increasing number of networked devices and services, and increasing the use of data intensive activities such as virtual reality and video conferencing. Cisco[45] predicts an annual increase in IP traffic of 22% in Western Europe between 2017 and 2022. We followed this increase up until 2022, but then assumed that increase would tail off to approximately 10% CAGR (Compound Annual Growth Rate) between 2023 and 2035.

We assumed a slight flattening of data consumption increases after 2025, since we needed to harmonise our estimates of bitrate increases (see Section 4.2.6) and OTT viewing hours. Total household data consumption is, in part, a function of IP video viewing hours and content bitrates. Based on our estimates of viewing hours and increased bitrates, if we followed a 22% CAGR increase of data consumption to 2035, we would see a significant reduction of the proportion of traffic that was for OTT. This seemed counter-intuitive to the prediction by Cisco, that video will be responsible for 82% of total IP traffic by 2022.

We have assumed that multicast IPTV data would be a negligible component of this total IP traffic (as measured by traffic using the internet backbone). This is because of the efficiency of multicast content, which is a one-to-many distribution method which sends data via the backbone once. This is consistent with the explanation provided in Section 3.4.3. As such, these estimates were only relevant to OTT.

An increasing data volume has implications for the model because it meant that less energy from the internet energy would be allocated to one hour of streaming. This is in line with studies that suggest that the internet network energy intensity (kWh of energy per Gigabyte transmitted) is decreasing as networks become more efficient. Aslan et al suggest that this intensity may be decreasing by as much as 29% per year [46].Given that our modelling assumes more moderate increases in data consumption, our estimates of improvements in energy per GB served are also more moderate, at approximately -7 to -13% CAGR to 2035 (depending on country being considered). This suggests an improvement in efficiency, but accounts for some diminishing returns in implementing such efficiency measures.

4.2.6 Bitrates of OTT and IPTV content

Whilst the earlier discussion has shown there will be some increase in efficiency of the internet in terms for the energy consumption per GB of data traffic. We also considered the fact that this may be offset by the increase in quality of video files.
An important trend in TV delivery is the increased demand and supply of higher-definition content as newer viewing devices improve picture quality and IP networks increase in their capacity to provide the bitrates required. As we use data volumes to

[44] Malmodin J, Lundén D. The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. *Sustainability*. 2018; 10(9):3027. https://doi.org/10.3390/su10093027
[45] Cisco Annual Internet Report https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html
[46] Aslan, J., Mayers, K., Koomey, J.G. and France, C. (2018), Electricity Intensity of Internet Data Transmission: Untangling the Estimates. Journal of Industrial Ecology, 22: 785-798. https://doi.org/10.1111/jiec.12630

allocate energy consumption, this is a key parameter to consider in future scenarios. In the absence of reputable studies to provide credible forecasts of bitrate, we have assumed an increase of video content from UHD and HD content over time.

To estimate this proportion, we estimated the percentage of content viewed in UHD, HD and SD in 2020. We then assumed an increase in UHD content in line with Cisco's forecast in the increase of UHD-ready televisions to 2025, with a plateau of growth from 2025 to 2035 of 10%, to be conservative. We then considered similar but more moderate increases in HD over time of 6%. A weighted average of bitrates can be used for each definition to calculate the increase in average bitrate for 2025, 2030 and 2035.

It is important to note that we did not find any publicly available data on the current proportions of viewing by each definition, so these were our best guesses based on the content bitrate used for 2020. We assumed a similar trajectory for IPTV, albeit with a higher starting point of proportions of content viewed in UHD and HD. Figure 9 outlines our estimate for OTT. Note that a similar analysis was completed for IPTV but is excluded for brevity.

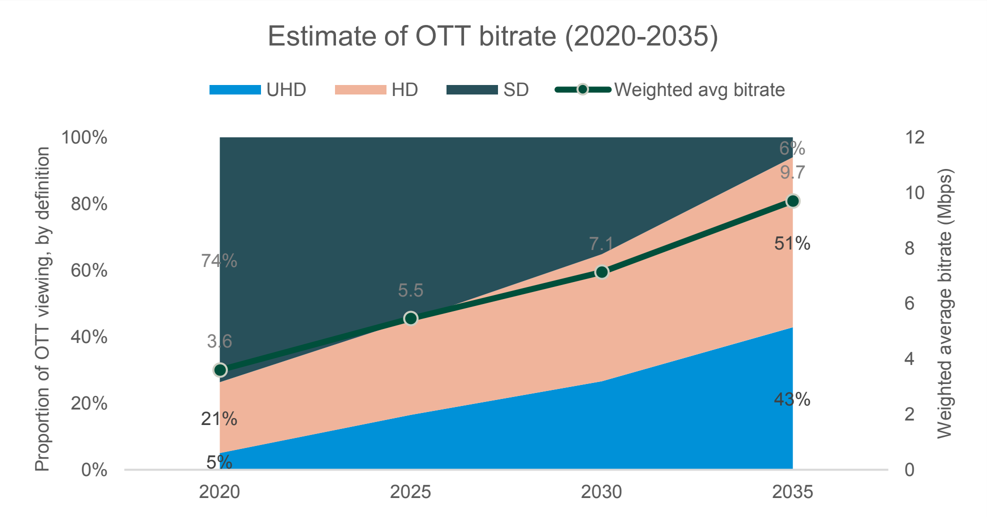


Figure 9. Estimate of OTT bitrate, based on assumed proportion of OTT viewing in each definition (UHD, HD, SD).

4.2.7 OTT and IPTV viewing methods

We also took into account how viewers may access OTT and IPTV content in the future. We assumed that as TVs are updated by consumers, there will be an increasing amount of OTT viewing that are direct to television, as opposed to via peripherals such as streaming devices and set-top boxes. This is because newer televisions are IP-enabled smart TVs that tend to have a wider range of OTT apps available to view this content. This changing trend was reflected across all Scenarios.

It was also assumed that some managed IPTV viewing would take place without a set-top box by 2035, as we are aware that some development is already taking place to make this possible. However, this is currently a nascent development so the reduction in STB use was kept moderate. For our modelling, we assumed a decrease of five percentage points every five years, such that in 2035, 20% of IPTV households were viewing content without a STB.

4.2.8 Home caching (Scenario D)

In some developing markets outside of Europe, a solution has been developed to counter the issues related to intermittent internet connection and viewed VOD content. This works by 'pushing' VOD content via non-IP distribution methods (DTT and satellite) to viewers' premises. This content is stored on a home caching device in a user's home[47]. When the user requests the content from their VOD app, the device would first check if the content is stored locally, and only if it is not available, it would request the content to be sent via IP networks. This enables high-quality content to be delivered even with intermittent internet service.

In a European context, where such networking issues may not be as common, such a home caching system could be speculated as a solution to reduce costs of content delivery networks, and reduce the unicast traffic via IP networks, especially for the most

[47] Under other scenarios not considered in this study, the television could have such a device embedded

widely viewed content. This may have some savings in terms of overall energy consumption of TV delivery, which is what is considered in Scenario D.

In defining the parameters for these devices, we considered the 'fat tail' of content that would be most eligible for caching. That is, the most popular content that is most likely to be requested by users. This operates under the assumption that a fraction of the hours in VOD providers' catalogues is viewed by a majority of users within a few weeks of its release. We also considered the possible number of VOD providers that would partner with network operators to use home caching.

We developed our model with in-depth modelling provided by Project Sponsors, that analysed and developed the assumptions behind what a viable but optimistic level viewing via home caching would be. The analysis took into account: consumer uptake, VOD platform participation, storage size of home caching device required, hours of reading time, and required bitrate of content delivery.

This was completed using primary data from French VOD platforms. This defined the total amount of content that was eligible for home caching, the amount of storage required to store the 'fat tail' catalogue, the user uptake of home caching, and the required bitrate of DTT multiplexes required to send the content in an off-peak window[48]. This enabled us to have a detailed look at the number of hours of content required to be stored to ensure an effective 'hit rate' (the proportion of content that is on the home cache device when requested by a user – as opposed to being requested via IP networks).

The key parameters used in the modelling are outlined in Table 3. These parameters represent an optimistic but possible scenario envisioned by the Project Sponsors.

Table 3. Home caching parameters used in Scenario D energy modelling

Parameter	**Value (by 2035)**
Total streaming via OTT avoided (which was replaced by viewing via a home caching solution send by DTT).	25%
Daily reading time of home caching devices	3.5hrs
On power of device (when caching and being used to view)	10 W
Standby power of device	0.5 W

The caching parameters were used to amend Scenario A, so that we could compare current trends. In effect, this meant that DTT would be responsible for a larger amount of viewing than in Scenario B, and VOD viewing growth via OTT would plateau as market penetration of home caching took effect. The split of viewing hours used for the analysis of Scenario D is outlined in Figure 10.

[48] Satellite was not considered as part of the energy modelling of this study, we assumed that all home caching content would be sent via DTT networks. However, it could feasibly be implemented via satellite also.

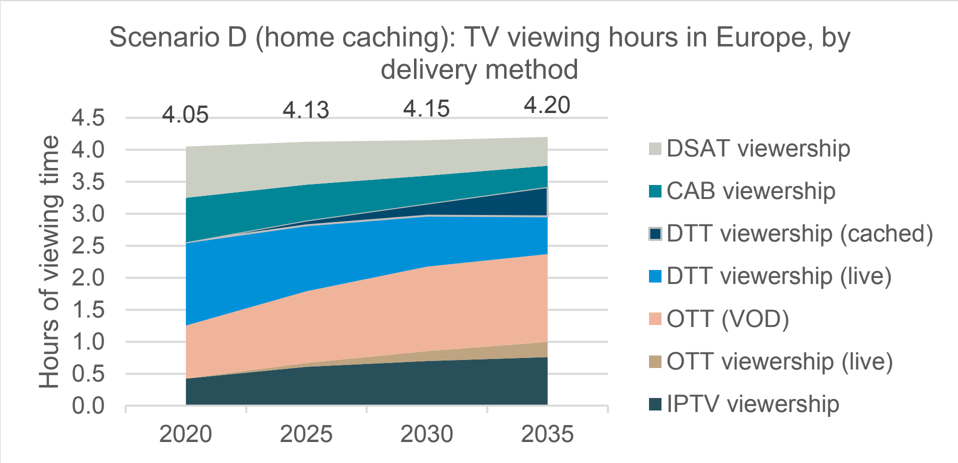


Figure 10. Scenario D breakdown of total viewing hours, assuming successful home caching.

5 Results

We found that the overall emissions and energy consumption of DTT networks was lower than for OTT and IPTV delivery methods across all European countries. This was mainly driven by the additional customer premises equipment and networks required to deliver television over the internet. Differences in country results tended to be driven by differences in the grid emissions factors.

Figure 11 outlines our estimates of the energy consumption and GHG emissions per viewing hour of TV for Europe. These are split by the three delivery methods considered in the study. In this section we have presented a selection of country-level results, and the pan-Europe estimates. A full tabulation of all countries is provided in Annex A.

The analysis suggests that DTT is the most energy-efficient delivery method, when compared to OTT and IPTV. IPTV was found to have the highest energy consumption allocated. This was due to the need for a set-top box for all viewing, as well as higher bitrates of content meaning that a higher amount of allocation for the access network and CPE (modem router) energy was needed. This was only slightly offset by the network efficiencies in the core internet network of multicast distribution.

OTT requires a higher energy consumption than DTT, driven by the internet network energy. However, this is still lower than IPTV consumption. The reason for this is due to a lower bitrate of content meaning less energy allocated in the delivery networks and modem/routers, and less average energy consumption of peripherals (either none needed, or the ability to use a lower-energy streaming devices).

The lower energy consumption of DTT was due to the efficiency of the networks, as well as the simplicity of the in-home network interface. Apart from a fraction of households requiring an antenna amplifier, the DTT antenna cable is typically connected directly to the TV without the need for an active device (with the exception of a small proportion of usage of antenna amplifiers). The one-to-many distribution method also meant that the energy consumption of the DTT transmission networks was relatively low when divided by the total viewing hours using the DTT. This is demonstrated by the breakdown provided in Table 4.

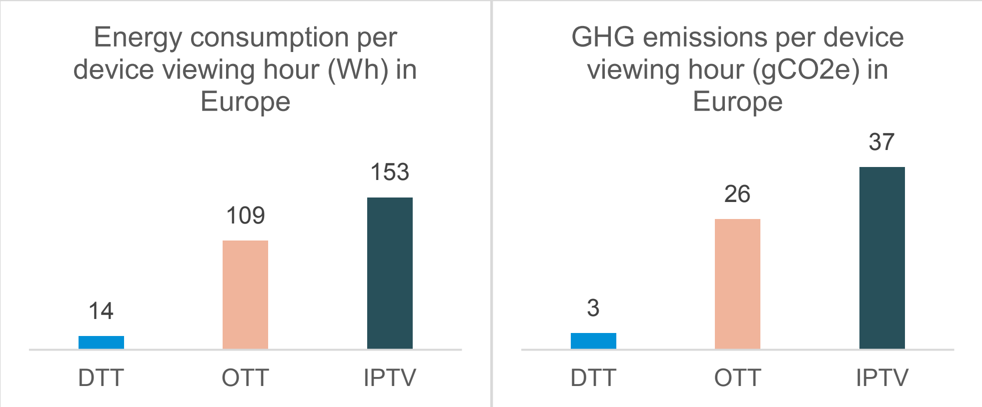


Figure 11. EU average estimates of energy consumption and GHG emissions for one-hour of TV viewing. Note these estimates exclude TV sets.

When we consider each component within each TV delivery system, we can synthesise each of the delivery methods into three fundamental components.

- **Distribution infrastructure:** All network components outside the home. For DTT this is the transmission networks. For OTT and IPTV this is the data centres and IP core and access networks.
- **In-home network interface:** Components in the home that receive data from the network infrastructure and distributed within the home. For DTT this would be the antenna and in some cases antenna amplifier. For OTT and IPTV this would be the modem/router.
- **Viewing peripheral**: Devices (excluding TV sets) used to view content. In some cases there would be no peripheral (if TV is connected directly to interface), but in other cases this may include a STB (all delivery methods, but most common for IPTV), streaming device (OTT), or gaming console (OTT).

Table 4. Breakdown of average energy consumption (Wh) for Europe by component

Component	**DTT**	**OTT**	**IPTV**
Distribution infrastructure (incl. data centres)	8	34	39
In-home network interface (e.g. amplifier, modem)	3	55	88
Viewing peripherals (e.g. STB, streaming devices)	3	20	26

Whilst our analysis excluded televisions, we conducted an analysis of the overall energy consumption if a nominal 56W television was included in the analysis. This was to understand the role of the ultimate viewing device in the overall emissions.

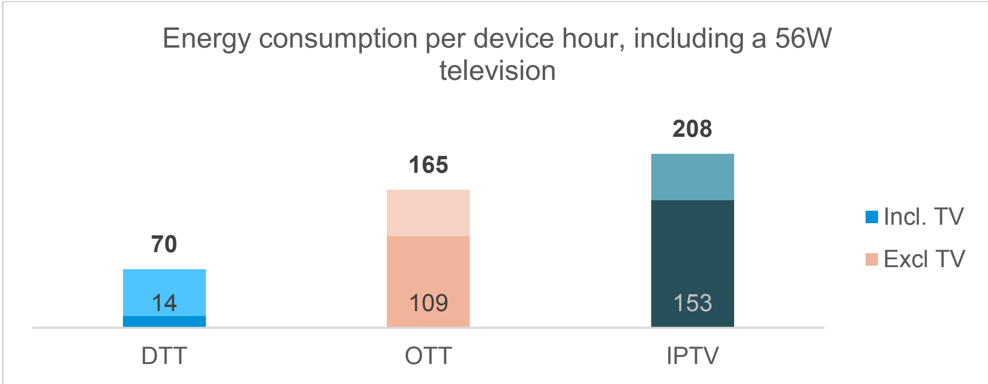


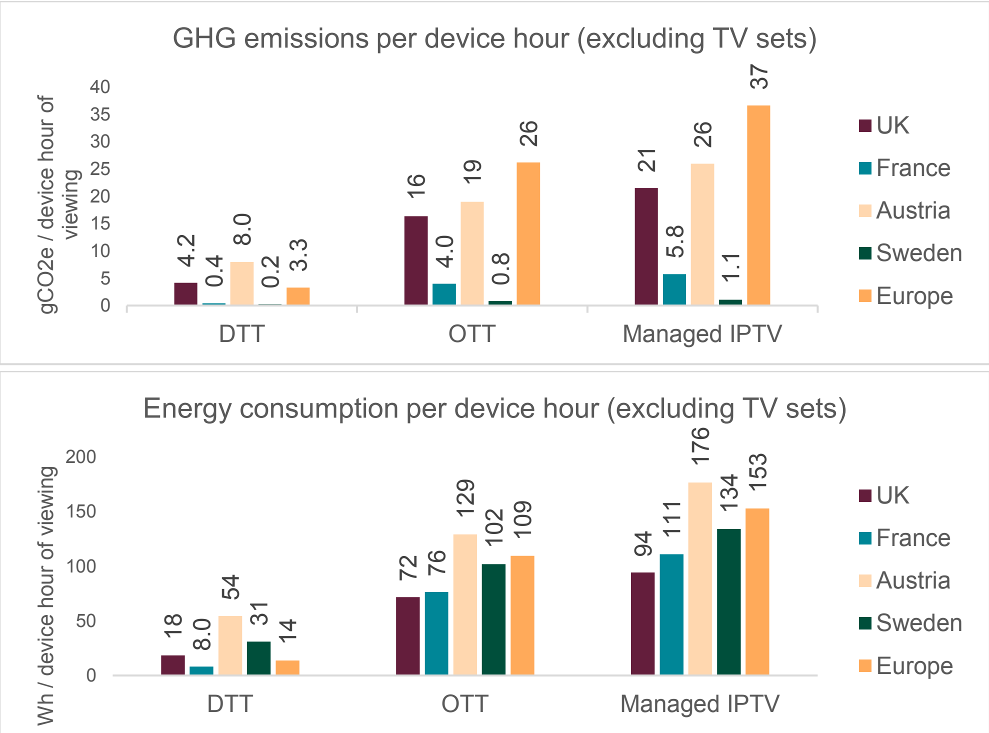
Figure 12. Impact of TV on energy consumption, by delivery method

For when considering energy consumption, as shown in Figures 13 & 14, there is still a clear difference between countries, even before emissions are applied. This is due to:

- **Viewership:** As DTT transmission is fixed, the efficiency of the delivery depends on the total viewership. If viewership is lower, there will be a larger allocation of network energy per viewing hour. For example, Austria has a lower DTT penetration thus we see a higher energy consumption per viewing hour.
- **Peripherals:** Consumer use of peripherals such as PVRs and STBs are likely to vary per country, which will have an impact on overall energy consumption.

- **Data volumes (OTT and IPTV):** Using our allocation methodology, energy consumption of CPE (modem/routers) is calculated based on the one hour of streaming data divided by the total volume of data consumed by a typical CPE (assumed to run 24/7). As total data volumes over fixed line networks varies by country, energy allocated to one hour of viewing will be higher in countries with lower data consumption, and lower for those with a higher data volume.

The key driving factor in the differing results for GHG emissions between countries, as shown in Figures 13, is the significant variation in emissions intensity of electricity generation across countries. For example, France and Sweden have a significantly decarbonised electricity grids when compared to many other European countries, which is why the GHG per viewing hour is significantly lower than the EU average.



Figures 13 & 14. GHG and energy per viewing hour of OTT, IPTV and DTT

5.1 DTT

The key drivers of DTT emissions varied depending on the country. For example, in the UK where complex STBs were found to be more common for DTT viewing, this component made up over half (excluding TV sets) of the overall energy consumption. These devices tended to have a high active standby to account for the fact that some of these would be complex STBs.

In other markets where DTT viewership was lower (but geographic coverage of DTT was still high), the broadcast infrastructure has a higher relative energy consumption, due to the distribution infrastructure being shared among fewer viewing hours. This was the case for Austria and Sweden, as shown in Figure 15.

In other cases, the broadcast infrastructure of DTT made up less than 15% of the overall footprint. It is also worth noting that the broadcast infrastructure exhibits no scaling behaviour as a result of increased viewership. This meant that the greater number of viewers, the lower the GHG footprint associated with the network infrastructure per viewing hour, or vice versa.

Another significant portion (~1.5 to 5Wh/hour) of the energy consumption was due to DTT aerial amplifiers. Little is currently known about the prevalence of these devices, but the assumption that they are always ‘on’ (it was expected that these devices are located in lofts or on top of buildings and not easily accessible to switch on an off) contributed to the emissions. This was a key uncertainty in the study, and more accurate data may have some impact of the results. However, even if the prevalence of aerial amplifiers doubled or trebled, this would not have a material impact on the conclusions relative to other delivery methods.

Where the television set was also considered, this increased the overall footprint by approximately four-fold. The television was included here for use as a reference point to compare with other studies.

Figure 15. DTT energy consumption for Europe and a selection of countries, by component

5.2 OTT

The modelling suggested that OTT was responsible for a higher GHG emissions per hour of content viewed. This was driven by the energy consumption of the customer premises equipment (modem routers), as well as a higher energy consumption of the internet infrastructure when compared to the DTT networking.

In addition, it was more common for OTT to be viewed using in-home peripherals such as set-top boxes or streaming devices, as opposed to connecting directly to the TV from the network interface (which is common in DTT). This meant an additional device consuming energy.

The key difference between OTT energy consumption between countries was the total data volume used in each household. The available data from Ofcom suggested that this was significantly higher for countries such as the UK than for France. Given that the energy consumption of the CPE was allocated by total data volume per household (as per the approach outlined in Section 3.3.4), this meant that for France, one hour of OTT content was allocated a higher proportion of the CPE energy consumption.

As in the DTT analysis, including the television set significantly increased the overall emissions, suggesting that for all viewing methods, the choice of viewing device was an important factor in overall emissions.

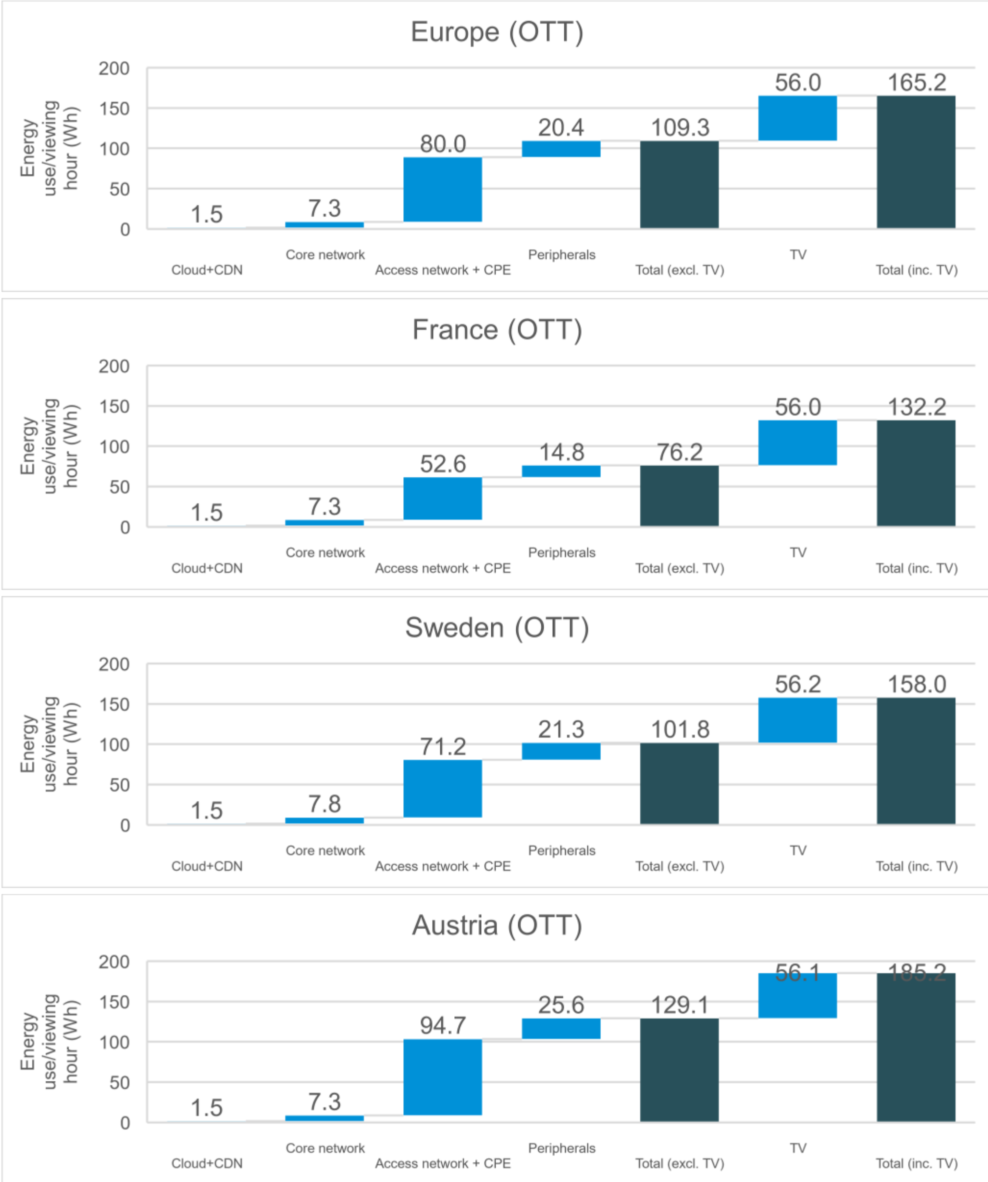


Figure 16. OTT energy consumption for Europe and a selection of countries, by component

5.3 Multicast IPTV

Generally, IPTV required a higher amount energy than DTT and OTT. Like OTT, a significant proportion of the GHG emissions was due to the internet network and customer premises equipment, which were required to transmit and receive content. The charts on the next page outline the breakdown of energy consumption by component.

The differences between the managed IPTV and OTT results were driven by three key factors. First, IPTV requires a STB for viewing content, meaning that 100% of viewing took place on peripherals. From the data that was available, as well as other studies, these generally had a higher power consumption when compared to typical streaming devices. This meant that peripherals had a higher proportion of the overall consumption.

Secondly, the bitrate of managed IPTV was assumed to be higher than that of OTT, meaning that a larger slice of the network was allocated to this service, as per earlier discussion on the allocation of energy by data volume.

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Finally, there were efficiency gains of multicast IPTV on the core network and CDNs energy consumption. In fact, we assumed that energy consumption of core networks and CDN to be negligible in the case of IPTV. These efficiencies were not able to be offset by the above two driving factors.

The charts on the next page also demonstrate the differences between countries. Again, this is primarily driven by allocating the energy consumption of the IP network (including home routers) based on data volume. In countries with a higher data volume per household, such as France and the UK, this meant that one hour of viewing was responsible for less energy of the overall infrastructure, when compared to countries with lower data volumes.

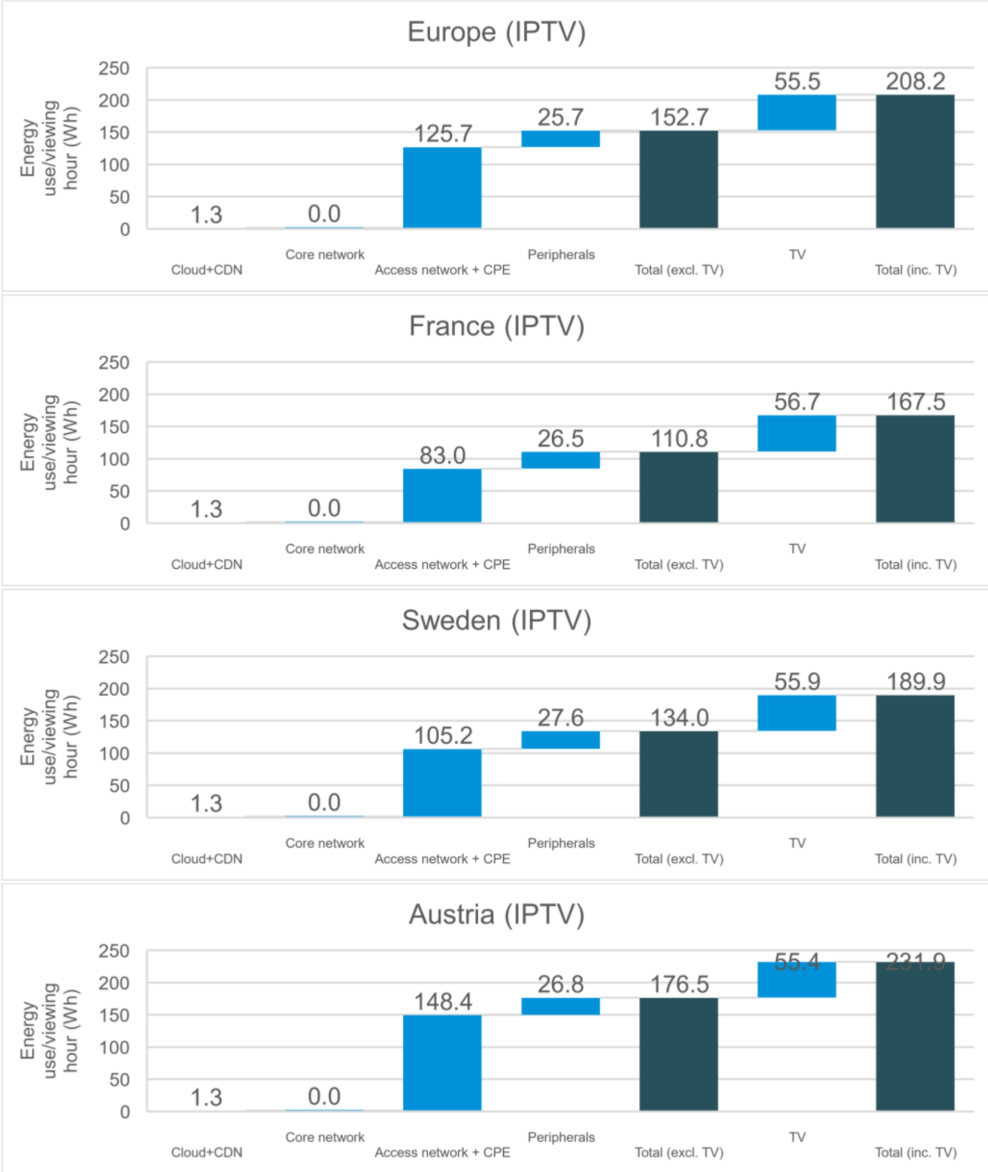


Figure 17. IPTV energy consumption for Europe and a selection of countries, by component

5.4 Baseline results in context with other studies

To sense check the results of our study, we were able to compare the results from other estimates. From the most recent estimates, notably those from the Carbon Trust and the BBC, we found very close alignment. These two studies were the most recent, but also the studies that utilised primary data from companies providing OTT services. For the other studies, we see that the results are generally in the same order of magnitude, which confirm that our approach is fit-for-purpose.

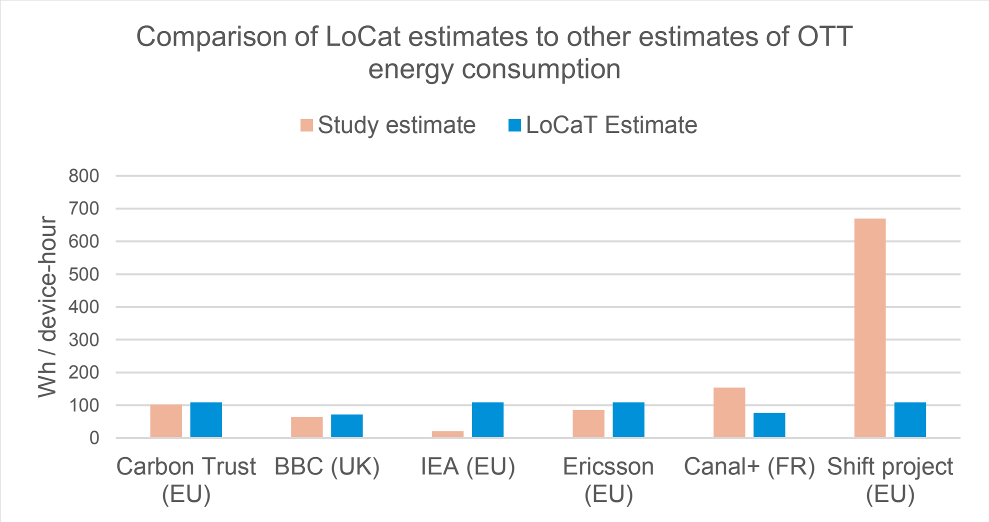


Figure 18. LoCaT OTT estimates when compared to other estimates of energy consumption. Note that for each study we have removed their published value for the television set, to be consistent with the results from this study.

It is important to note that these studies all included televisions in their estimate. Based on the parameters provided in these studies, we have removed the television to make the results comparable to those of this study.

There are some studies where there wasn't such an alignment. For example, the Shift Project. These estimates have been directly disputed by the IEA, as well as indirectly based on the convergence of other studies on a much smaller number. This was especially due to their assumptions about the energy intensity of internet networks and the bitrate of content.

Some of the minor variations in the results were due to differing assumptions and scopes. These are generally related to the network intensity of IP networks, and the power consumption of peripherals. This is to be expected for modelling complex systems, and where some of the above studies were considering the impact of one OTT service (e.g. BBC iPlayer) as opposed to a nation- or Europe-wide estimate.

5.5 Scenarios results

A comparison of the total energy consumptions of the modelled scenarios is provided in Figure 19. For simplicity, we have presented in this report the results of our modelling of the EU28 combined. For scenario results from the other countries where we ran scenarios – France and Austria – refer to Annex B. Our analysis suggests that overall energy consumption tended to be lower for scenarios that had a higher proportion of DTT, scenarios C and D. Only when DTT viewership share became very low (less than 2%) did DTT's unit energy impacts increase to the point where they were close to the unit impacts of OTT and IPTV.

For Scenario B, where DTT remained in operation but reduced to a significantly lower proportion of penetration, our analysis shows a higher energy consumption overall when compared to Scenario A. In the case of Scenario C, where we have modelled a resurgence of DTT for viewing linear content, we see a 5% reduction in that calculated total emissions of DTT, IPTV and OTT when compared to the baseline scenario A. Similarly for Scenario D, where home caching is used to displace non-linear and time-shifted viewing hours that would otherwise be delivered OTT delivery, our model suggests a further reduction in energy consumption.

Qualitatively, these findings are aligned with what was found in our 2020 baseline modelling, which demonstrated the lower energy consumption of DTT. The results of the scenarios analysis suggests that the same holds true when we run the modelling using parameters that speculate about the future direction of TV trends.

Note that this analysis is unable to provide a calculation of the total energy consumption of TV viewing, because we have not modelled the energy consumption of cable and satellite. However, the trends of cable and satellite viewing hours were held the same across all scenarios, which means we were able to compare the cumulative impacts of DTT, OTT and IPTV on a like-for-like basis. As such, we have expressed the scenario comparison in terms of total energy of DTT, IPTV and OTT.

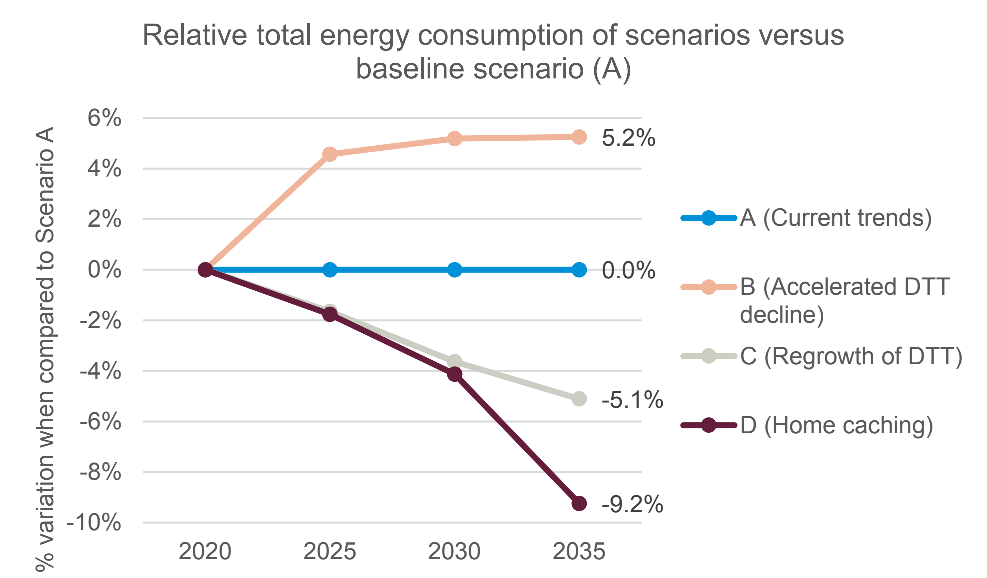


Figure 19. EU28 Comparison of Total Energy Consumption of OTT, IPTV and DTT, when compared to the baseline case where current trends continue

Further, we were able to provide a snapshot of annual energy consumption for the total across DTT, IPTV and OTT in our scenarios, based on the scenario parameters in 2025, 2030 and 2035. Figure 20 outlines this annual energy consumption and GHG emissions snapshot for each scenario in 2035. This quantifies the absolute energy consumption and GHG emissions results shown in Figure 19.

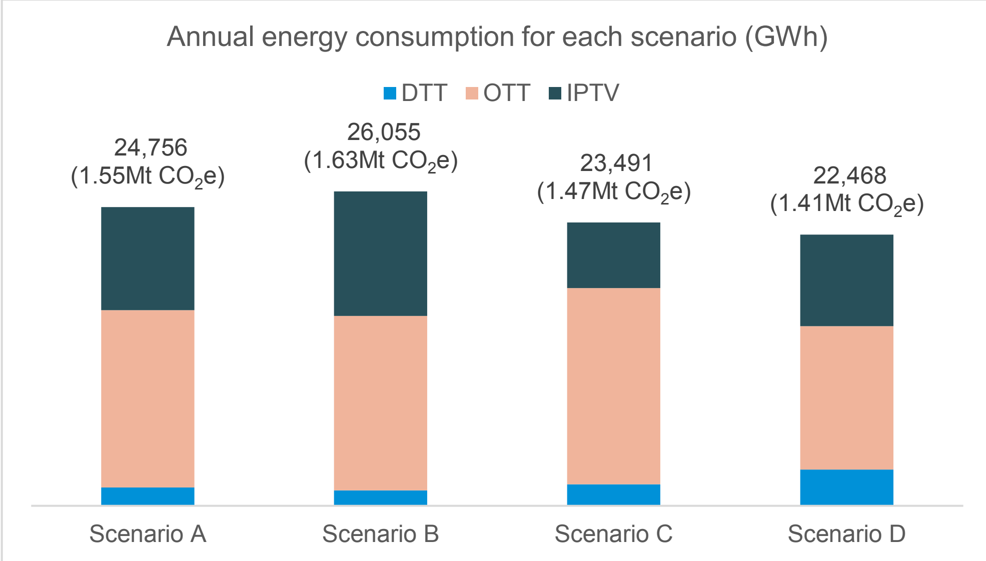


Figure 20. Energy consumption and GHG emission 2035 snapshot for each scenario for Europe

What cannot be modelled explicitly in the scenarios is the potential impact that DTT may have in reducing peak demands of IP networks, and the energy implications of this reduction. As a mainly linear distribution method, trends where viewers switch from DTT to live OTT *en masse* would significantly increase data flowing through the IP networks during peak viewing hours. Others have commented that the key driver for increased energy consumption in IP networks is the peak demand, not average data volumes sent via the internet. As such, we can speculate that an increase in OTT may have some impact on overall energy consumption, but this cannot be confirmed or quantified in this study, as the internet peak demand may be the combination of driving factors that are not related to TV.

In the next sections, we look at how the unit energy consumption changes between scenarios.

5.5.1 Scenario A: Baseline IPTV growth

Under Scenario A, which aims to estimate the carbon impacts if current trends continue, we see the efficiency of IPTV and OTT improve over the period to 2035. This is mainly due to improvements in network efficiency, supplemented with a reduction in the usage of peripherals used as direct-to-tv methods become more common for both OTT and IPTV.

We also see DTT energy consumption per device hour increase when compared to 2020 but remains significantly lower than OTT and IPTV. The main driver for the increase is that fewer viewing hours via DTT are sharing the energy required to operate the network, which was assumed to be constant in this study. Even with this increase, we still see that DTT requires significantly lower energy that OTT and IPTV.

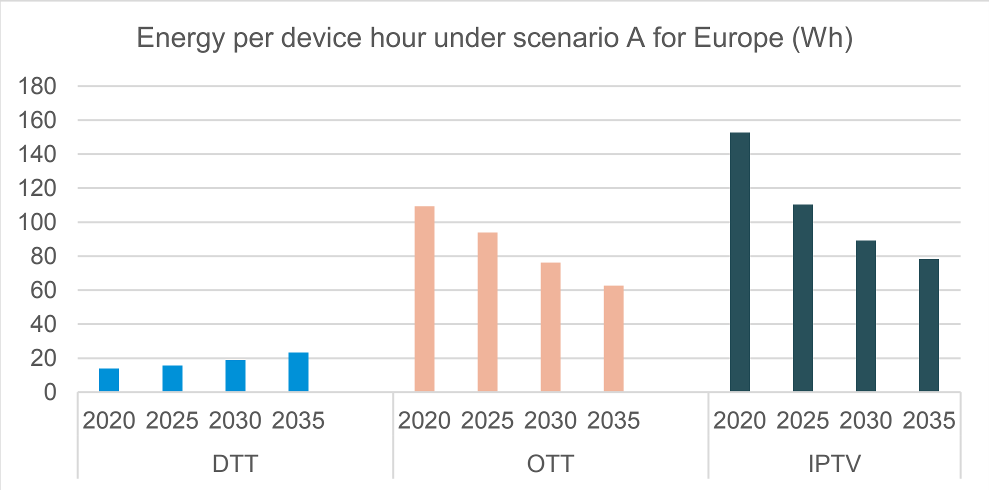


Figure 21. Scenario A results for unit energy consumption per device hour

5.5.2 Scenario B: Accelerated IPTV growth

In the scenario where DTT viewership declines more steeply, we observe similar trends to Scenario A, however the changes become sharper. An increase in the usage of IPTV and OTT (including OTT for viewing linear content) means that one device hour of IPTV and OTT would be allocated a lower amount of the network energy.

For DTT, we see the unit energy per hour increase more sharply than in Scenario A. However, this still remains lower than the OTT and IPTV unit energy consumption – 14% lower than OTT and 30% lower than IPTV. This is even with the DTT network energy being shared among even fewer viewing hours.

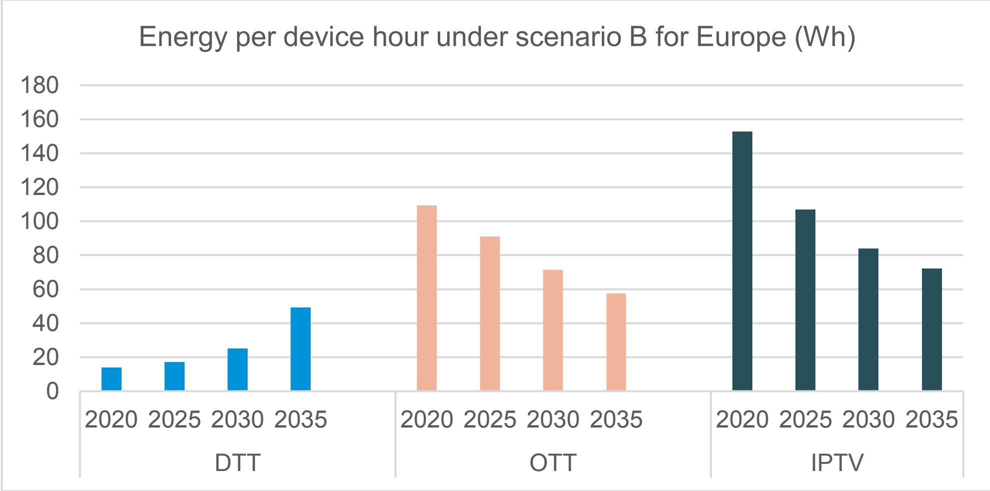


Figure 22. Scenario B results for unit energy consumption per device hour

5.5.3 Scenario C: Plateau of IPTV and growth of DTT

In a scenario where DTT continues to be used for a considerable proportion of viewing hours, the unit energy impacts of DTT remain low well into the future. 3 shows that OTT and IPTV do not realise the same efficiency gains as in earlier scenarios, as each hour of viewing is allocated a higher proportion of the network energy.

Our modelling suggests that this would decrease the overall energy from OTT, IPTV and OTT, as demonstrated earlier in Figure 19.

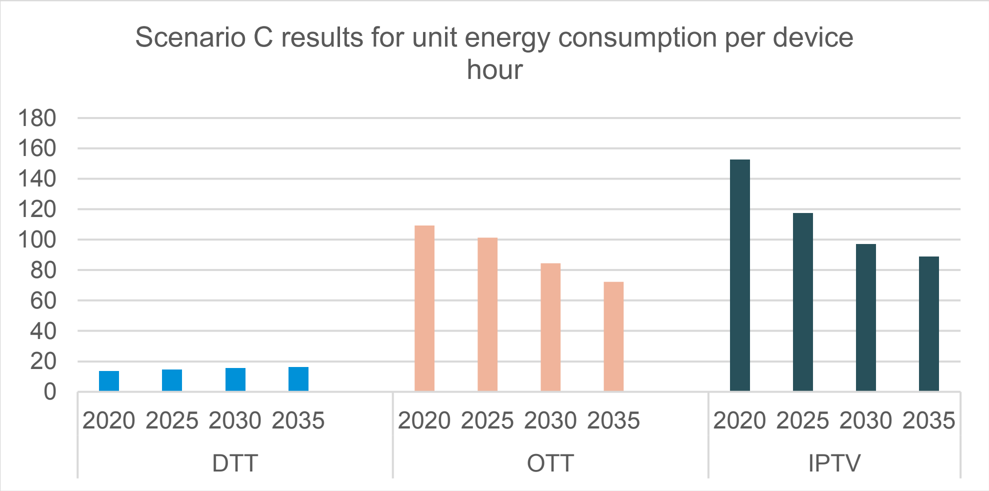


Figure 23. Scenario C results for unit energy consumption per device hour

5.5.4 Scenario D: DTT home caching for VOD viewing

In scenario D, as outlined in Figure 24, we see an increase in the unit carbon impacts of DTT. This is due to the increased energy consumption of the home-caching devices themselves, but this is offset by the higher viewing hours of DTT spread between a larger proportion of viewing hours. This increase is still minimal when compared to the unit impacts of OTT and IPTV, which have similar efficiencies to the results in Scenario A.

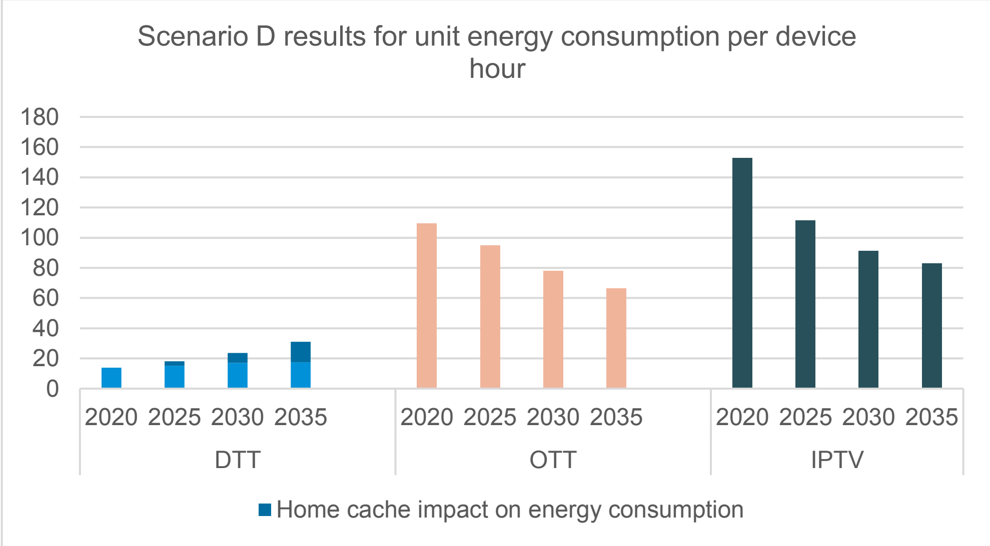


Figure 24. Scenario D results for unit energy consumption per device hour

The EU modelling suggests that the home caching model had the least amount of energy allocated to it, when comparted to all other scenarios. This can be explained by the fact that the consumption of the home caching devices has is offset by the reduced viewing hours via OTT.

5.6 Embodied emissions

Previous sections of this report have focused on the use use-phase of TV delivery. That is, the emissions associated to the energy consumed in the operation of viewing and delivering TV content. The embodied emissions of a physical product or infrastructure, however, are the emissions caused by producing these products or network components[49]. It is commonly estimated based on the energy required to extract and transport the raw materials, and the manufacturing process to transform the raw materials into a finished product. This section provides some indicative and exploratory analysis of the embodied emissions associated with the devices and infrastructure considered in the study.

While there are several methods used in the literature to estimate the embodied emissions, the one chosen for the purpose of this study build on previous studies and life cycle assessments to calculate the embodied emissions as a function of the energy usage on the use phase. The methodology uses a ratio defined as: (gCO2e embodied) / (Wh used in the operation).

The starting point for this methodology is the distribution of carbon emissions over the whole lifetime of the device/infrastructure. We used the ratios provided by the ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard which indicates, for example, that for a medium chassis router, 85% of the emissions occur at the Use stage, and only 15% at the Embodied phase. On the other hand, for example, an LED/LCD monitor will have 20% of its emissions in the Use phase and 80% as embodied. This difference shows how various devices have a distinct profile, which reflects how much material they contain, but also how frequently they are used. In this example, a TV is turned “On” for a few hours a day, while a router will be “On” almost permanently. The expected lifetime is also a factor influencing this. For this reason, all the calculations were done on a granular level by device type.

As this ratio is expressed in CO2e emissions and these differ by country for the use phase, based on the grid factor, we first did a conversion to Wh assuming a global grid emissions factor for the embodied portion, which was assumed constant for our calculations (most devices are produced in similar regions and shipped across to the countries where they are used).

In Table 5 below, the last column (Embodied gCO2e per Wh use) was applied to the LoCaT study results (use phase) to estimate the embodied emissions for each country. While the results show an interesting picture, it is worth noting that there is a high degree of uncertainty involved in the methodology, as in every embodied emissions calculation.[50]

Table 5 Embodied emissions: Calculation of Embodied/use phase ratio

Component	Use phase CO2e (%)	Embodied CO2e (%)	Reference grid intensity (g/kWh)	Use phase ((Wh)	Embodied (gCO2e per Wh use)
DTT Infrastructure	95%	5%	500	190	0.03
Servers (cloud and CDN)	95%	5%	500	190	0.03
IP networking infrastructure	90%	10%	500	180	0.06
Home router	85%	15%	500	170	0.09
Home peripherals	80%	20%	500	160	0.13
TV	20%	80%	500	40	2.00

It is therefore understood that embodied emissions are not considered as a main component of the LoCaT study. The degree of uncertainty behind them could potentially

[49] Embodied Carbon: Factsheet, UCL https://www.ucl.ac.uk/engineering-exchange/sites/engineering-exchange/files/fact-sheet-embodied-carbon-social-housing.pdf
[50] E. Fryer, “Evaluating the Carbon Impact of ICT: The Answer to Life, the Universe and Everything: Understanding the Limitations of LCA Based Carbon Footprinting Methodologies,” Intellect, UK http://www.greendigitalcharter.eu/wp-content/uploads/2016/07/Evaluating_the_carbon_impact_of_ICT.pdf

mask some of the nuances picked up by the more accurate and precise modelling of the emissions in the use phase.

Nevertheless, the scale and relevance of the embodied emissions, as briefly estimated, point to an important insight. Prolonging the life of infrastructure and devices currently in use could play a significant role in reducing the emissions associated with TV viewing or – to be precise – avoid a significant increase in these emissions by changes that would require mass replacement of older devices. Avoiding a radical change in infrastructure and devices, which could cause a premature obsolescence of those currently in use, should be a factor for consideration in any policy decisions.

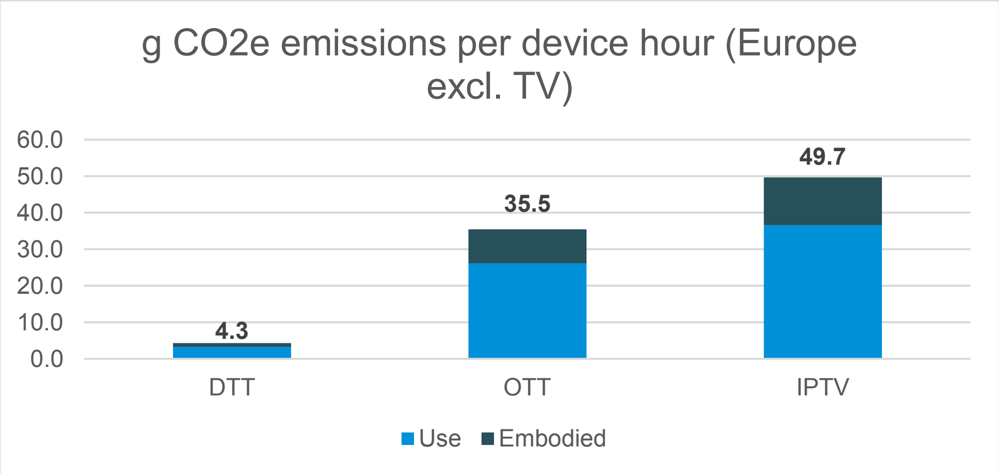


Figure 25 Embodied emissions for Europe

It is important to note, that this is a very high-level preliminary analysis that does not consider any primary data of device manufacturing. As such, we have not combined this with the more rigorous use-phase emissions which forms the major thesis of this report.

6 Conclusions

This report analyses the delivery of TV content across the different delivery methods. We find that the energy consumption and associated emissions of DTT are an order of magnitude lower than estimates for OTT and managed IPTV. This is true in the base case of 2020 and across our future scenarios. The report analyses all 27 EU countries as well as the UK and provides an overall estimate for the EU28 on average. This pattern is the case across all countries, but the reduction in emissions is most pronounced in countries with higher DTT penetration.

Whilst care was taken to use the most up-to-date data and validated assumptions, we stress that there is still inherent uncertainty in our modelling. This is especially the case for in-home peripheral, as well as network modelling, where there is limited data at the country level. Data from internet service providers on the energy consumption of their networks, as well as the implications of increased demands on their network, would be a valuable contribution to this analysis.

It is also expected that video streaming organisations and broadcasters will have a detailed knowledge of their own audience, including their viewing time and choice of devices. This may have impacts on the organisation-specific estimates of energy consumption per viewing hour and may provide more accurate figures than the country-level average estimates produced in these studies. A common methodology for undertaking this would be beneficial in order to allow companies to benchmark against each other, and to provide a streamlined way to report these estimates to their stakeholders.

Although there is uncertainty in the modelling, the results – including the lower energy consumption associated with DTT – is aligned with analysis conducted by the BBC. This suggests that this is a more energy efficient method for delivering linear TV content.

Annex A: Summary of 2020 results for all EU28 countries

Unit energy and GHG impacts of TV delivery, by country (excluding TV sets) for 2020

	Energy consumption (Wh / device hour)			GHG emissions (gCO_2e / device hour)		
	DTT	**OTT**	**Managed ITPV**	**DTT**	**OTT**	**Managed IPTV**
Europe	13.8	109.3	152.7	3.3	26.2	36.6
Austria	54.3	129.1	176.5	8.0	19.0	25.9
Belgium	21.9	98.9	136.6	3.8	17.2	23.8
Bulgaria	10.8	116.2	158.0	4.6	49.3	67.0
Croatia	7.4	82.3	115.8	1.0	11.0	15.6
Cyprus	15.8	94.2	127.3	10.1	60.5	81.7
Czechia	9.3	138.1	176.4	4.0	59.6	76.2
Denmark	19.9	105.9	137.7	2.2	11.9	15.4
Estonia	27.6	78.6	106.7	20.6	58.7	79.6
Finland	31.4	112.2	146.5	2.8	10.0	13.0
France	8.0	76.2	110.8	0.4	4.0	5.8
Germany	15.3	138.2	189.0	5.2	46.7	63.9
Greece	7.8	158.9	203.1	4.7	96.3	123.1
Hungary	16.0	99.3	135.4	3.6	22.5	30.6
Ireland	13.6	131.2	168.8	4.3	41.5	53.3
Italy	12.5	188.9	243.7	2.9	44.0	56.8

	Energy consumption (Wh / device hour)			GHG emissions (gCO_2e / device hour)		
	DTT	OTT	Managed ITPV	DTT	OTT	Managed IPTV
Latvia	21.0	121.5	164.7	3.1	18.2	24.7
Lithuania	13.6	108.9	148.5	1.1	9.0	12.3
Luxembourg	26.4	95.7	131.2	2.2	8.1	11.1
Malta	28.3	103.0	138.9	10.1	36.8	49.6
Netherlands	13.4	110.5	150.2	5.2	43.1	58.6
Poland	6.8	125.3	154.0	5.1	94.1	115.7
Portugal	9.3	63.6	85.7	2.4	16.2	21.8
Romania	7.7	163.0	205.1	2.2	47.1	59.3
Slovakia	11.4	115.1	151.2	1.4	13.8	18.1
Slovenia	15.3	77.5	106.5	3.7	18.7	25.7
Spain	6.9	94.2	133.0	1.4	19.5	27.5
Sweden	31.1	101.8	134.0	0.2	0.8	1.1
UK	18.3	71.6	94.2	4.2	16.3	21.5

Annual estimated energy consumption and GHG emissions, by country (excluding TV sets) for 2020

	Total annual device hours (billions)			Annual energy consumption (GWh)			Annual GHG emissions (tonnes CO2e)		
	DTT	**OTT**	**Managed ITPV**	**DTT**	**OTT**	**Managed IPTV**	**DTT**	**OTT**	**Managed IPTV**
Europe	149.4	94.7	53.4	2,057	10,350	8,151	492,913	2,480,268	1,953,347
Austria	0.3	1.5	0.6	16	191	98	2,411	28,008	14,462
Belgium	0.6	2.3	2.4	13	226	329	2,331	39,373	57,231
Bulgaria	2.1	1.3	1.0	22	155	162	9,507	65,511	68,640
Croatia	2.2	0.6	0.7	16	53	77	2,242	7,068	10,290
Cyprus	0.5	0.2	0.2	8	20	25	5,328	13,095	15,786
Czechia	3.9	2.1	0.5	36	286	94	15,579	123,701	40,549
Denmark	0.9	1.2	0.6	17	127	78	1,897	14,193	8,683
Estonia	0.4	0.3	0.3	10	20	34	7,596	15,226	25,426
Finland	1.1	1.2	0.5	33	129	79	2,962	11,507	7,034
France	21.9	12.7	21.5	176	967	2,385	9,153	50,269	124,000
Germany	4.2	14.4	5.1	65	1,983	962	21,807	670,366	325,023
Greece	8.0	2.0	0.4	62	317	72	37,854	191,819	43,788
Hungary	1.3	1.9	2.0	21	188	264	4,786	42,495	59,692
Ireland	0.8	0.8	0.2	11	110	27	3,321	34,872	8,388
Italy	40.6	10.6	0.4	507	1,993	88	118,102	464,265	20,461
Latvia	0.6	0.4	0.2	12	46	40	1,829	6,912	5,997
Lithuania	0.9	0.5	0.4	12	58	65	969	4,783	5,432

	Total annual device hours (billions)			Annual energy consumption (GWh)			Annual GHG emissions (tonnes CO2e)		
	DTT	OTT	Managed ITPV	DTT	OTT	Managed IPTV	DTT	OTT	Managed IPTV
Luxembourg	0.1	0.1	0.1	2	11	17	170	977	1,408
Malta	0.1	0.1	0.1	4	9	10	1,308	3,381	3,492
Netherlands	1.9	3.3	2.4	26	359	357	10,166	140,199	139,393
Poland	10.5	6.9	1.3	72	868	193	54,037	651,493	145,223
Portugal	1.9	1.9	3.9	18	119	338	4,483	30,352	86,144
Romania	2.4	3.6	0.4	19	583	88	5,360	168,447	25,492
Slovakia	1.3	1.0	0.5	15	114	73	1,782	13,661	8,717
Slovenia	0.6	0.4	0.7	9	31	70	2,207	7,528	16,830
Spain	25.0	7.2	5.9	172	680	784	35,690	140,737	162,349
Sweden	1.2	2.0	1.1	37	208	149	297	1,664	1,192
UK	23.9	14.6	3.3	437	1,048	311	99,573	238,851	70,900

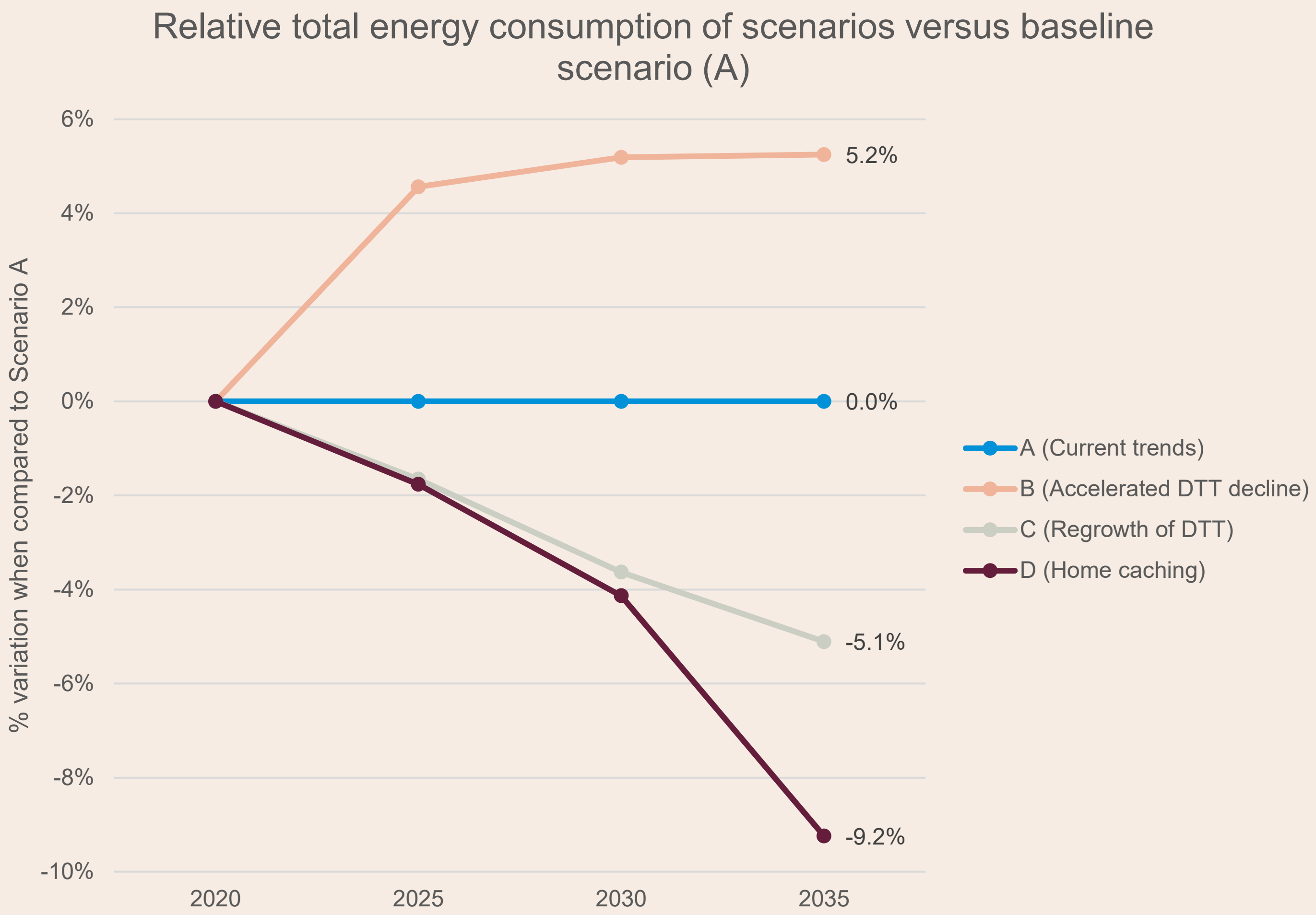
Annex B: Scenario parameters and results for Europe

Please refer to attachment.

Scenario parameters and results for Europe

Annex B

Scenario results for Europe



Scenario A: Baseline IP growth (based on current trends)

Scenario B: Accelerated IPTV growth

Scenario C: Plateau of IPTV and growth of DTT

Scenario D: DTT home caching for VOD viewing

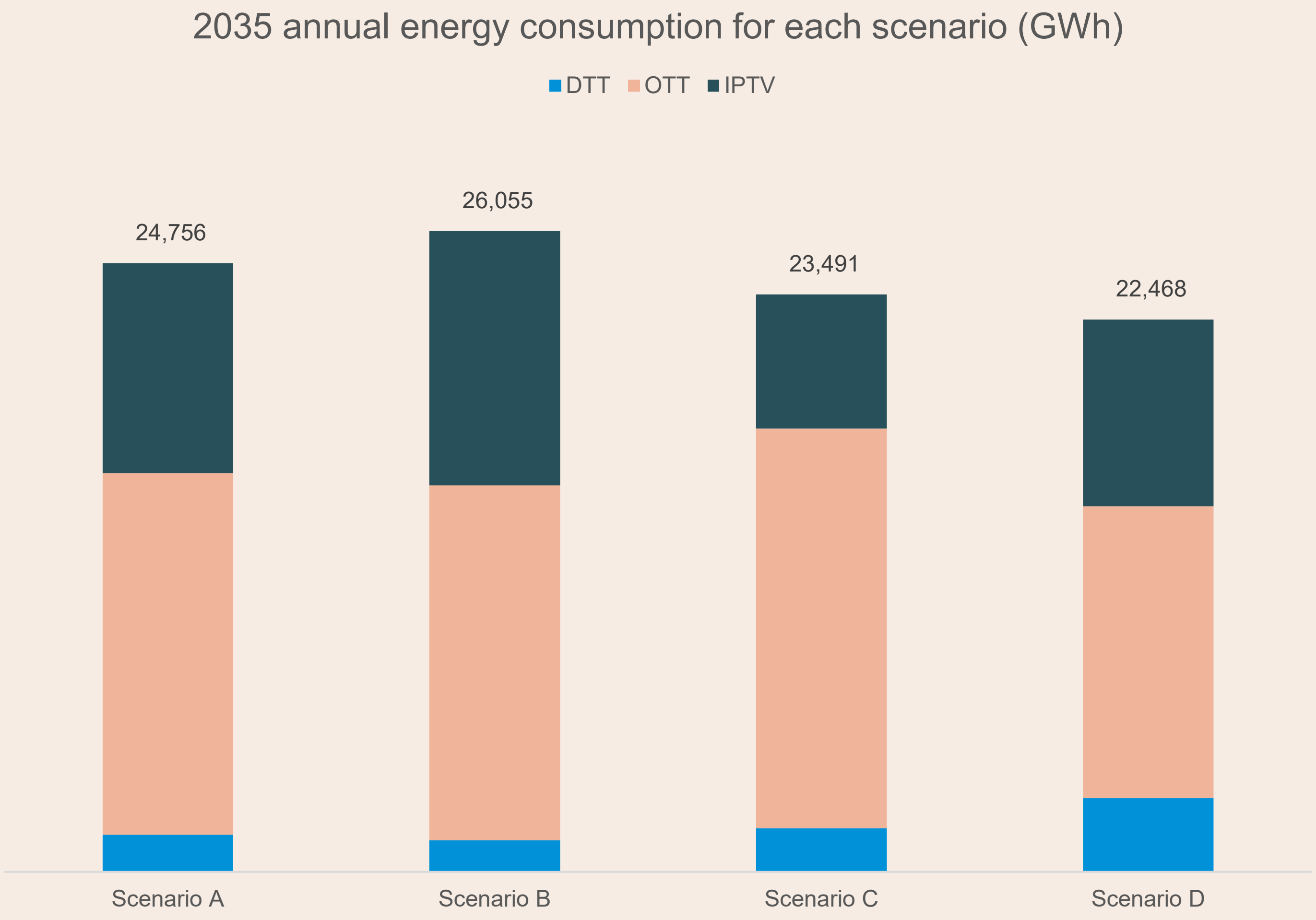
Scenario results for Europe – total energy 2035 snapshot

Scenario A: Baseline IP growth (based on current trends)

Scenario B: Accelerated IPTV growth

Scenario C: Plateau of IPTV and growth of DTT

Scenario D: DTT home caching for VOD viewing

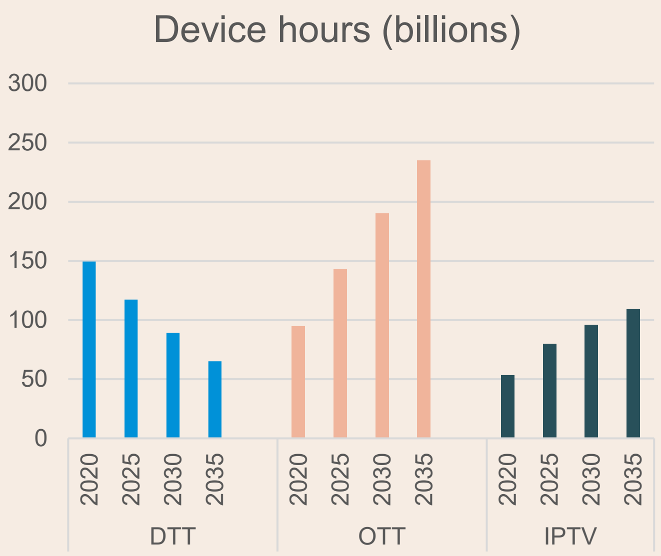


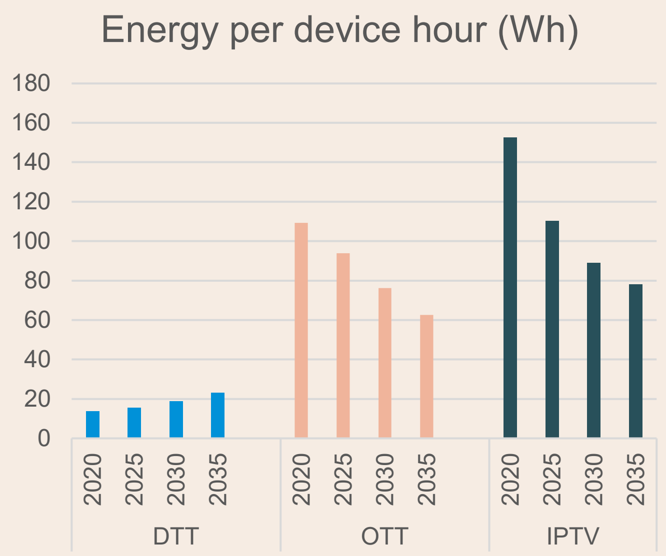
Scenario parameters for Europe – Scenario A

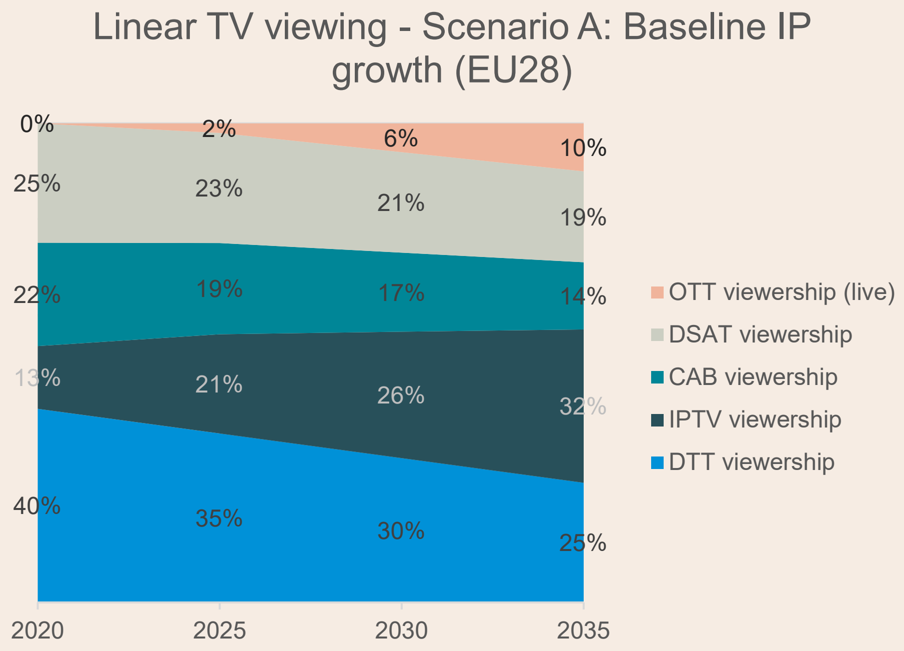
Note that all parameters are held constant across the scenarios, with the exception of those in section 4 below, which is intended to demonstrate the impacts of viewing by delivery method under different future circumstances.

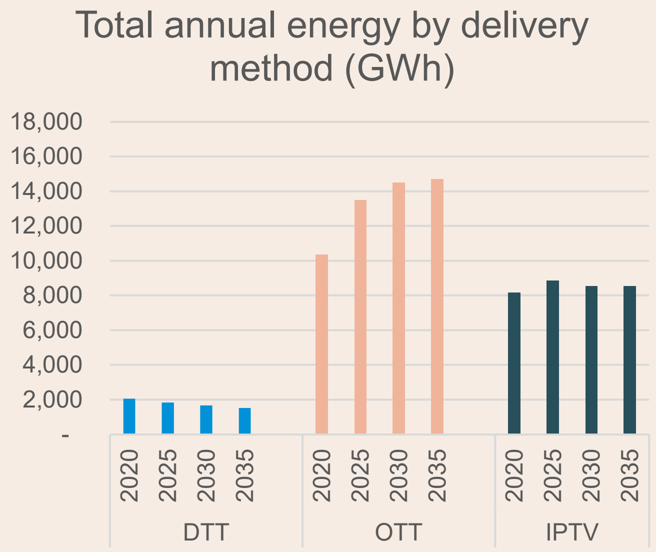
Category	Ref	Parameter	Units	2020	2025	2030	2035
1. Demographics	**1.1**	Population	People	514,871,046	517,997,063	518,921,599	519,133,662
	1.2	Total households	HHs	221,730,723	223,076,952	223,475,106	223,566,432
2. Grid emissions	**2.1**	Emissions factor for electricity generation (EEA)	kgCO2e/kWh	0.2397	0.1629	0.0862	0.0627
3. TV viewing trends	**3.1**	TV households (as a % of total)	%	94.0%	92.5%	91.0%	89.5%
	3.2	Linear as % of viewing	%	90%	85%	80%	75%
	3.3	% time-shifted viewed via OTT (vs. PVR/cached)	%	95%	95%	95%	95%
	3.6	Total daily TV viewing hours per person (linear & time-s	hrs	3.56	3.41	3.26	3.11
	3.5	VOD viewing hours	hrs	0.83	1.20	1.51	1.83
	3.6	Total TV viewing hours	hrs	4.05	4.13	4.15	4.20
4. TV viewing by delivery method	**4.1**	DTT viewership	%	40%	35%	30%	25%
	4.2	IPTV viewership	%	13%	21%	26%	32%
	4.3	CAB viewership	%	22%	19%	17%	14%
	4.4	DSAT viewership	%	25%	23%	21%	19%
	4.5	OTT viewership (live)	%	0%	2%	6%	10%
5. DTT networking and interface	**5.1**	Network energy consumption	kWh	[redacted]			
	5.2	% HHs with antenna amplifier	%	20%	20%	20%	20%
	5.3	% viewing via STB (simple)	%	5%	4%	3%	2%
	5.4	% viewing via STB (complex)	%	10%	8%	7%	5%
6. IP networking	**6.1**	Energy intensity of core network	kWh/GB	0.0051	0.0024	0.0015	0.0010
	6.2	Data consumption per capita	GB/person	70.09	99.63	163.88	270.27
	6.3	Average bitrate of content (OTT)	Mbps	3.20	4.85	6.34	8.63
	6.4	Average bitrate of content (IPTV)	Mbps	5.00	5.83	7.40	10.94
7. OTT viewing	**7.1**	% viewing direct to TV	%	19%	26%	34%	42%
	7.2	% viewing via streaming device	%	12%	10%	8%	6%
	7.3	% viewing via gaming console	%	18%	15%	13%	11%
	7.4	% viewing via IP-enabled STB	%	40%	35%	30%	25%
	7.5	% viewed via non-TV device	%	11%	13%	14%	15%
8. IPTV viewership	**8.1**	% viewing via STB	%	100%	95%	90%	80%

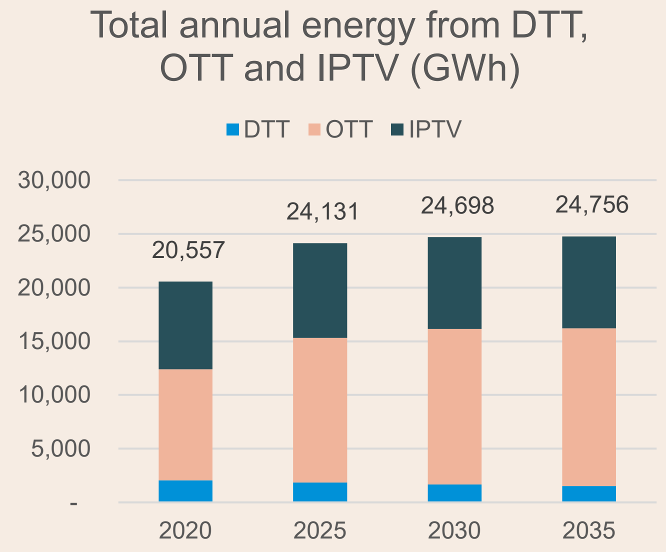
Scenario A: Baseline IP growth





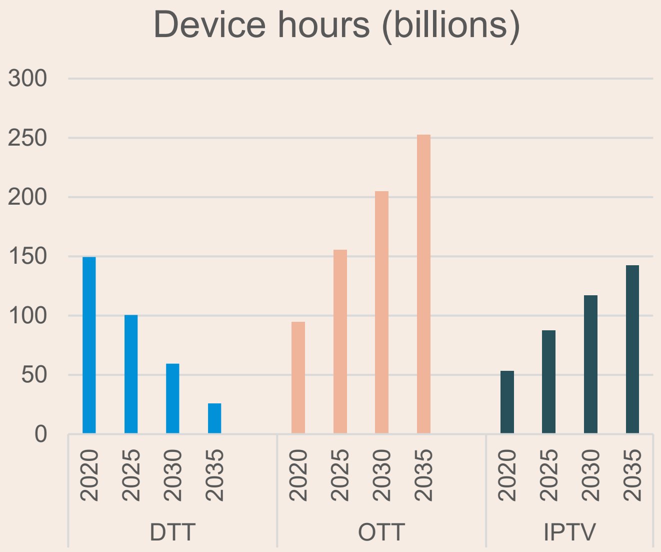


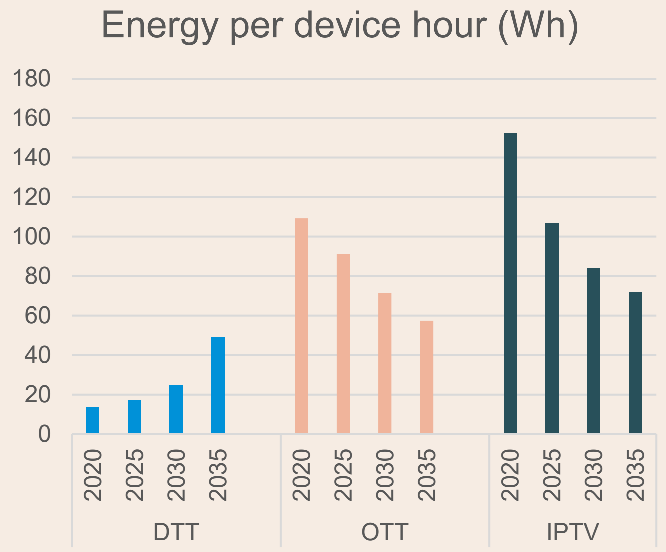


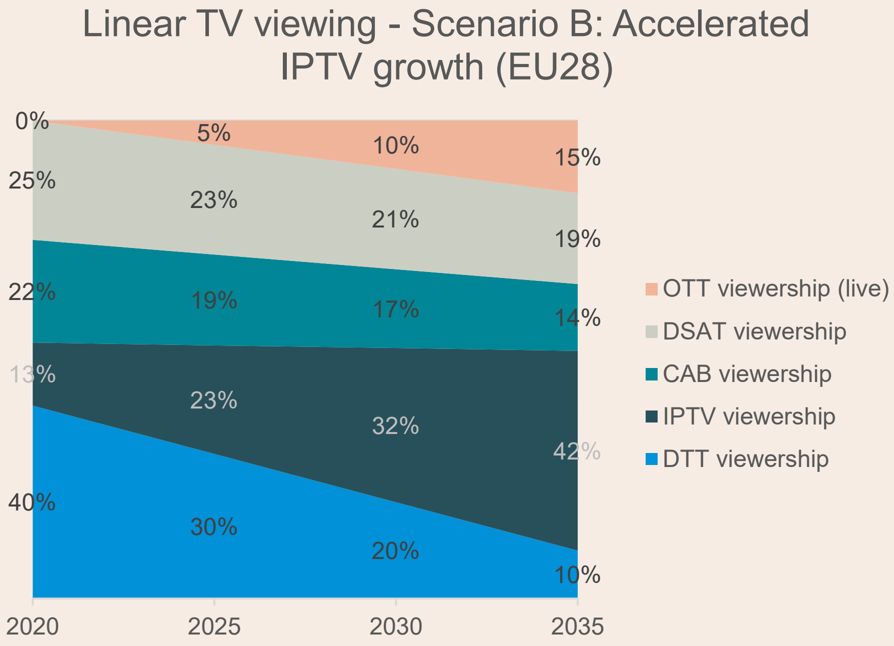


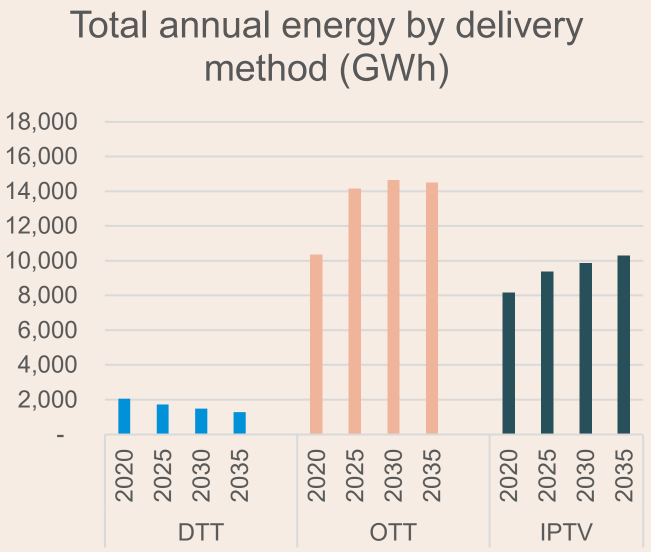
Note that any increase in total energy consumption may be offset by a decreased proportion of viewing for cable and satellite, which is not considered in this analysis

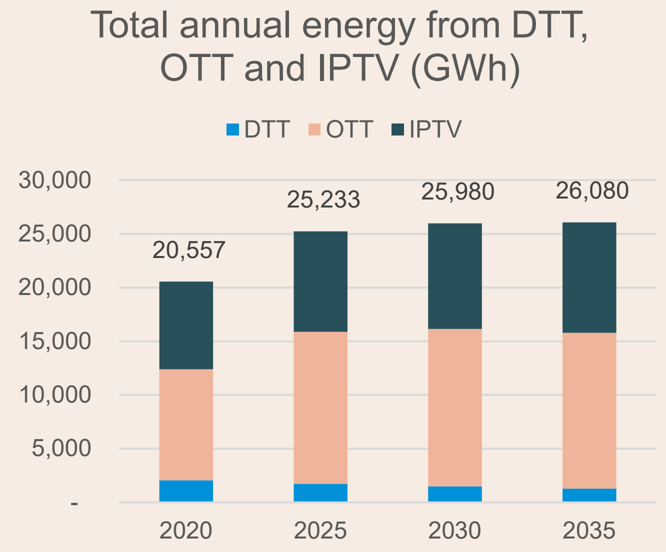
Scenario B: Accelerated IPTV growth





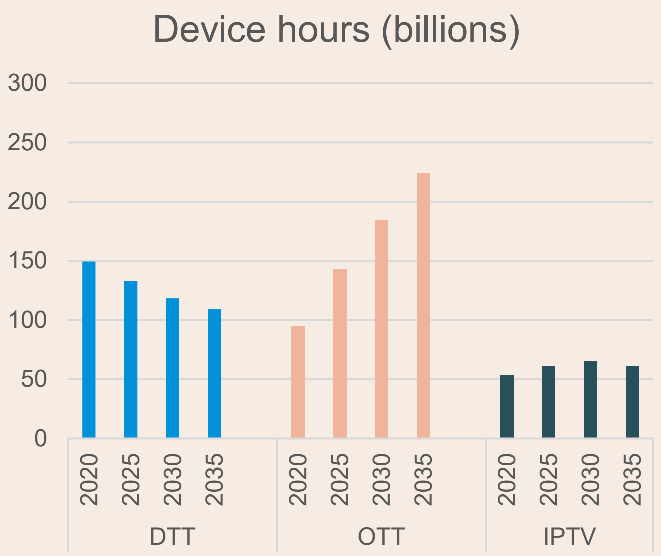


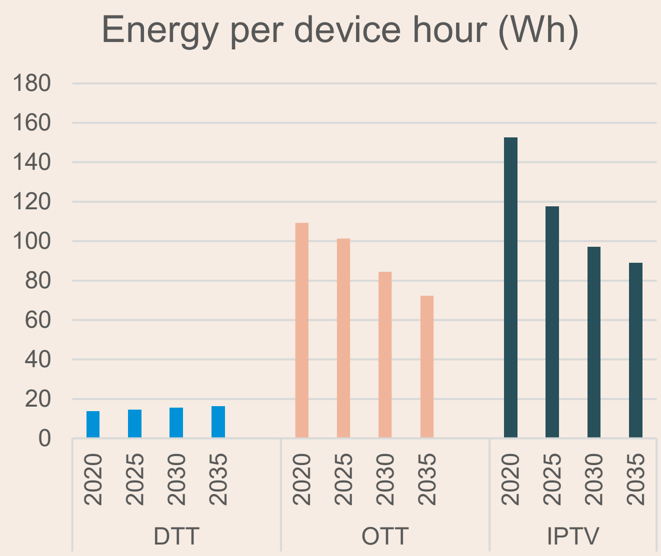


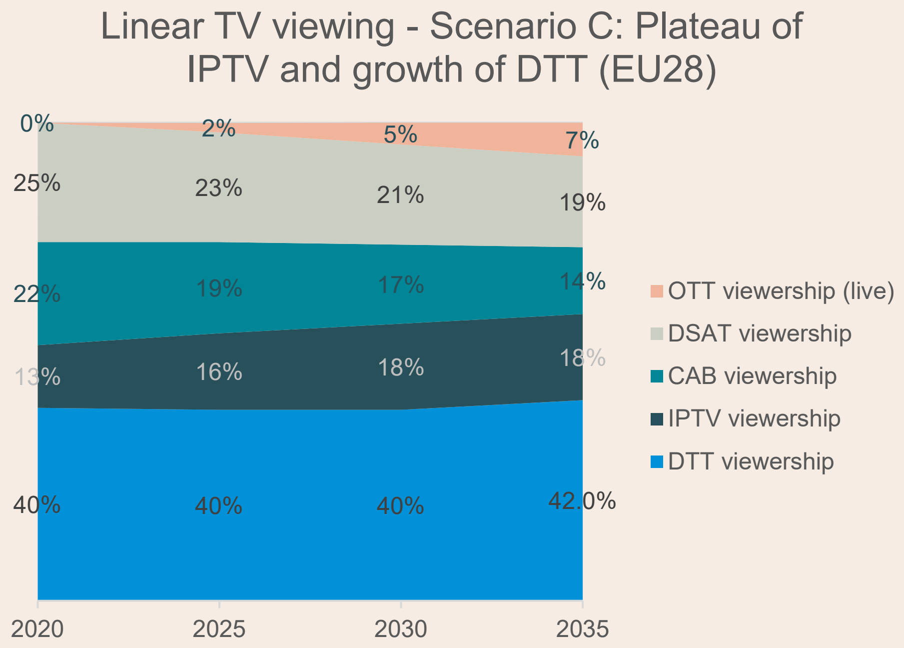


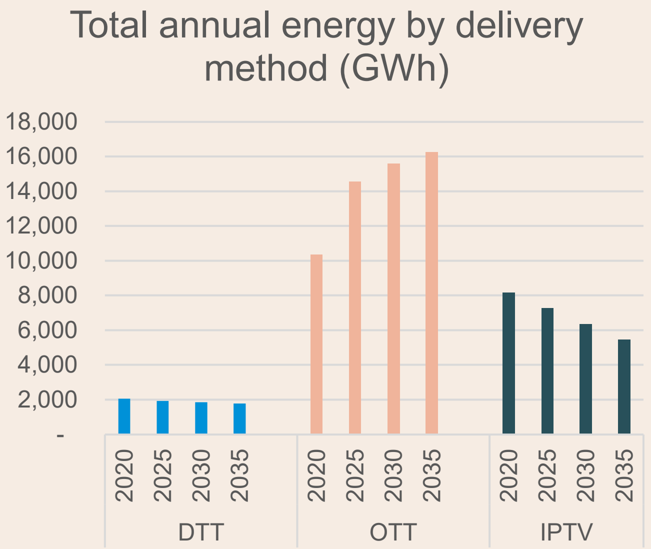
Note that any increase in total energy consumption may be offset by a decreased proportion of viewing for cable and satellite, which is not considered in this analysis

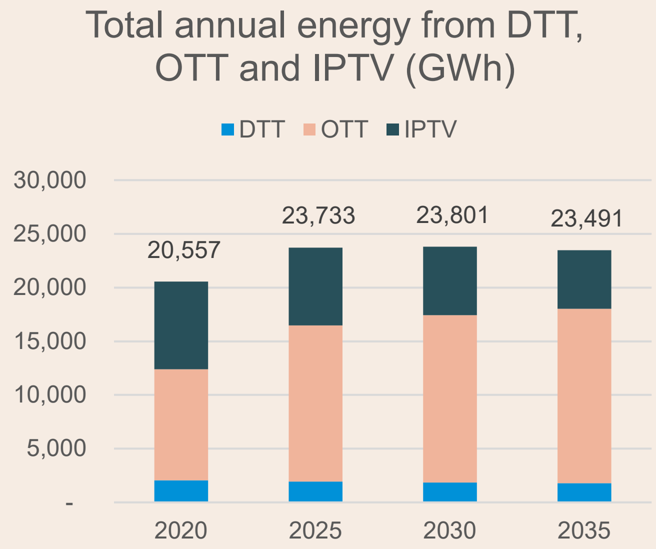
Scenario C: Plateau of IPTV and growth of DTT







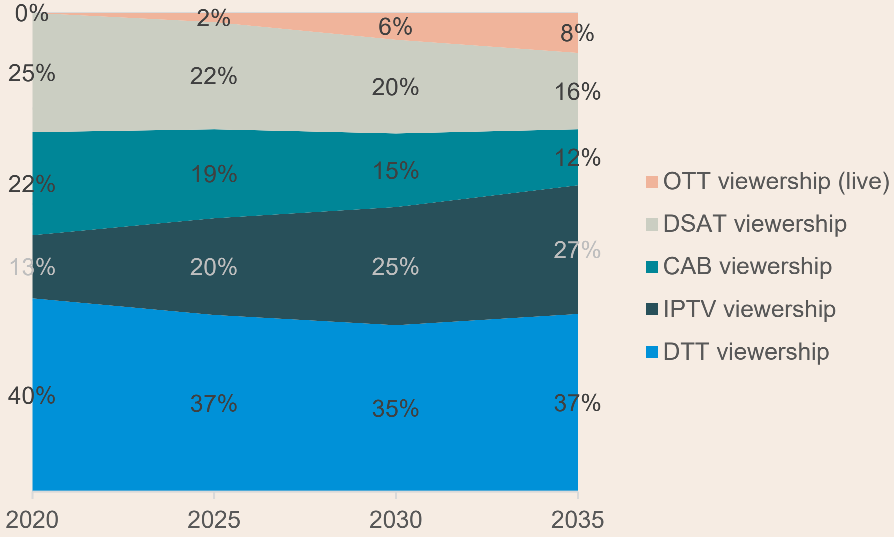




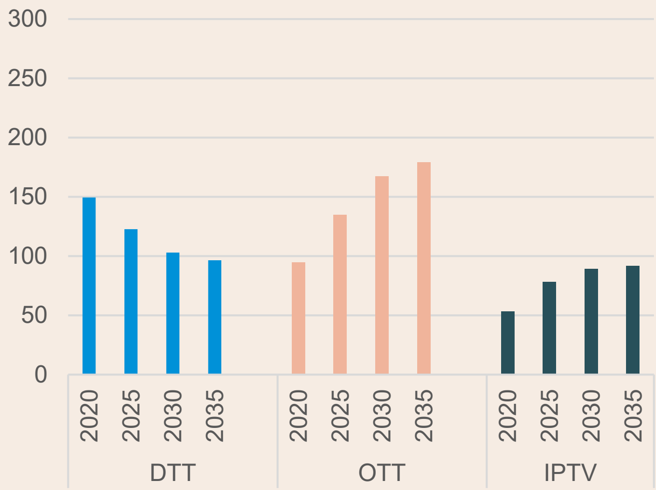
Note that any increase in total energy consumption may be offset by a decreased proportion of viewing for cable and satellite, which is not considered in this analysis

Scenario D: DTT home caching for VOD viewing

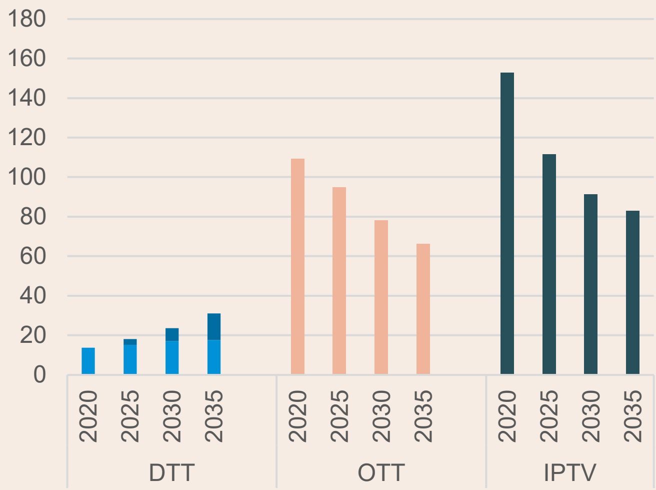
Linear & cached TV viewing - Scenario D: Home caching (EU28)



Device hours (billions)

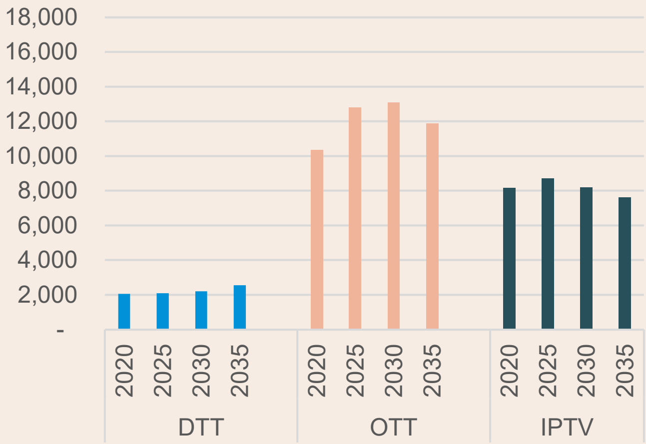


Energy per device hour (Wh)

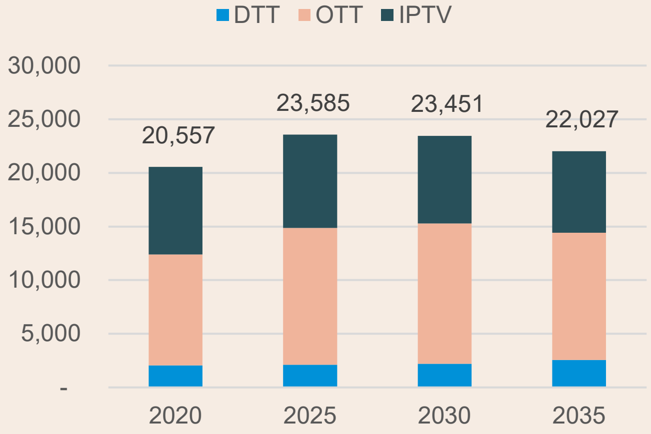


* Dark blue bar shows additional energy of home caching devices

Total annual energy by delivery method (GWh)



Total annual energy from DTT, OTT and IPTV (GWh)



Note that any increase in total energy consumption may be offset by a decreased proportion of viewing for cable and satellite, which is not considered in this analysis